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Cunninghamia 1(4), 399–466 (1986)

THE VEGETATION OF THE EURUNDEREE SAND MASS, HEADLANDS AND PREVIOUS ISLANDS IN THE MYALL LAKES AREA, NEW SOUTH WALES

P. J. Myerscough and R. C. Carolin

(Accepted for publication 30.9.1985)

ABSTRACT

Myerscough, P. J. & Carolin, R. C. (School of Biological Sciences, University of Sydney, New South Wales, Australia 2006) 1986. The vegetation of the Eurunderee sand mass, headlands and previous islands in the Myall Lakes area, New South Wales. Cunninghamia 1(4): 399-466. Of 17 plant communities recognized as occurring in the Eurunderee embayment, Myall Lakes, New South Wales, 13 occur on sand and are the particular concern of this paper. Community recognition was based upon qualitative field observation. As well, the identities of six were checked using species-pair associations based on point-quadrat data. Similarities between 13 communities were examined using species frequencies; ordering of the communities in terms of similarities apparently reflects environmental gradients in both drainage and presumed soil nutrient status. A Principal Coordinate Analysis was carried out on nine of the sand-based communities, also using species frequencies. The first two axes seemingly reflect the same environmental variables as in the similarity analysis: average height of the surface above the water-table and relative age of the sand surface which is assumed to be inversely proportional to soil nutrient status. Ecotones between some of the communities were examined and are mostly fairly sharp except for those between Wet Heath and Dry Heath.

Variation of the Eurunderee vegetation is discussed in relation to land systems present, vegetation of other areas of coastal sand and Quaternary changes on the eastern Australian coast. Age, hydrological characteristics, degree of podzolization and nutrient stocks of the sand surfaces all appear to be important in variation of the vegetation. As age and degree of podzolization increase in freely draining sand surfaces, plants that are highly sclerophyllous, many of which have well developed underground organs such as lignotubers, are increasingly apparent in the vegetation.

INTRODUCTION

Coaldrake (1961) showed that vegetation on the coastal sands in eastern Queensland could be related to the land systems present. This paper describes the vegetation of part of the Myall Lakes area in relation to the characteristics of its land systems, particularly those of the sand masses.

The Eurunderee area

The area considered here (Figure 1) is between the lake systems and the ocean from Mungo Brush to Smiths Lake and Seal Rocks, and is designated the Eurunderee area using the name of the parish in which most of it lies. It includes the Eurunderee embayment as defined by Thom, Polach & Bowman (1978) and the Eurunderee and Seal Rocks embayments as defined by Thom, Bowman & Roy (1981), and most of it is within the present Myall Lakes National Park.

Osborn & Robertson (1939) outlined its physical and climatological features. Engel (1962), Packham (1969) and Newey (1973) gave details of its geology, while aspects of its geomorphology and palaeohistory were described by Thom (1965, 1973), Carolin (1971), who drew extensively on Shepherd's (1970) work, Thom *et al.* (1978) and Thom, Bowman & Roy (1981).

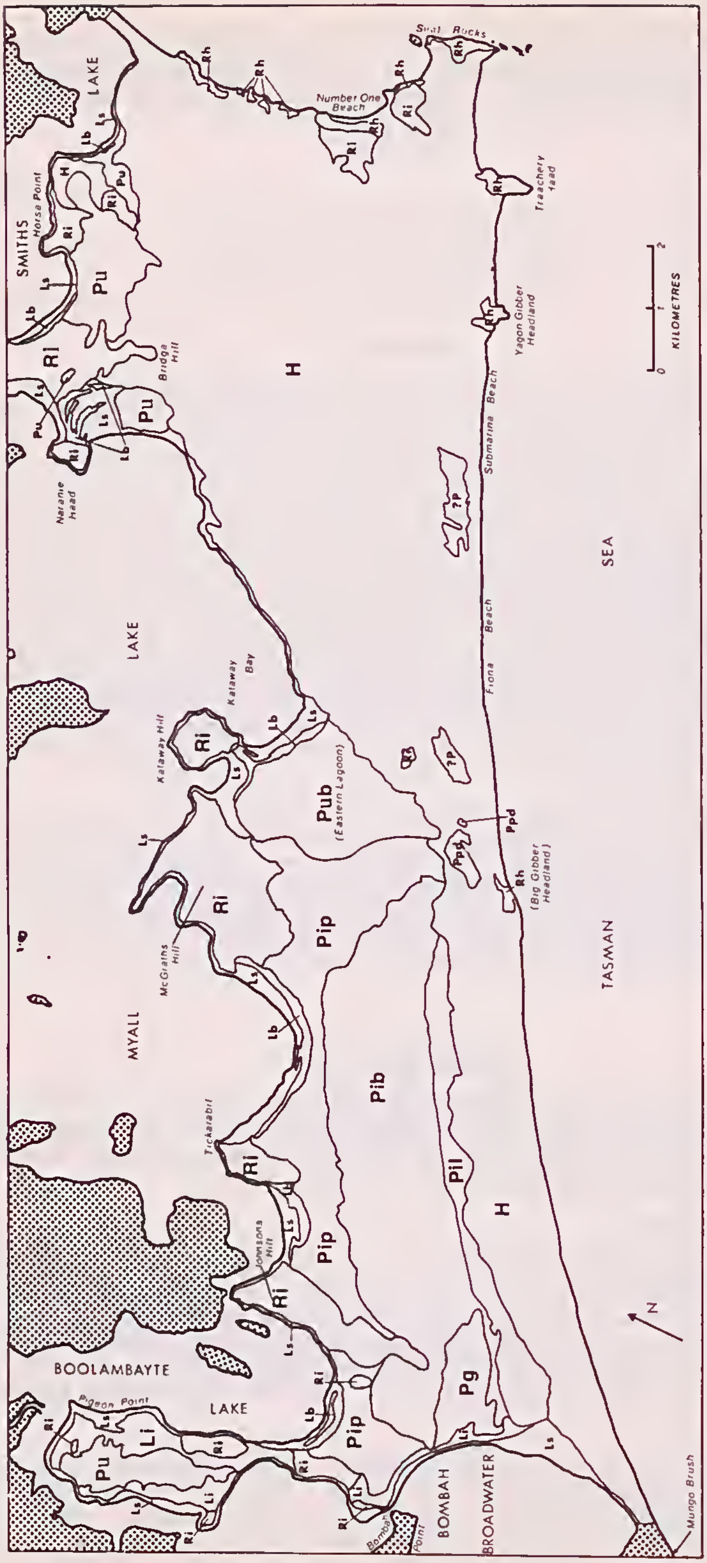


Figure 1. Eurunderee land systems map. See Table 1 for explanation of symbols. Land stippled was not part of the study area and accordingly was not assigned to land systems. The map base used was an enlargement of the 1:70 000 map of Myall Lakes National Park published by the Central Mapping Authority of New South Wales in 1981 with retouching of shorelines against the three appropriate 1:25 000 maps (Bombah Point, Myall Lakes & Seal Rocks) also published by C.M.A. (1977, 1977 & 1974 respectively). Mungo Brush, mentioned in the text, is just beyond the western boundary of the map on the southern shores of Bombah Broadwater.

Land systems

A land system was defined by Christian (1952) and Christian & Stewart (1953) as "an area, or group of areas, throughout which there is a recurring pattern of topography, soils and vegetation". Characteristic recurrent patterns are apparent in the topography, soils and vegetation of the area considered here, and land systems and sub-systems could be readily recognized based largely on their geological and geomorphological characteristics and their soils. These land systems and sub-systems were useful in categorizing the various land surfaces present in the area (Table 1) and in mapping their distributions (Figure 1), and in examining variation in vegetation with respect to them.

Other studies of vegetation and lands on coastal sands have used this type of approach to relate variation in vegetation to other features of land surfaces (Coaldrake, 1961; Gibbons & Downes, 1964; Specht, 1972; Ingwersen, 1976; Heyligers, Myers, Scott & Walker, 1981). Each of these studies defined categories of land surface in somewhat different ways, so it is not easy to work out equivalences between the categories used in the various studies and between those categories and the land systems and sub-systems of this study.

In this study four land systems are recognized (Figure 1 & Table 1). As with many other Australian lagoon systems (e.g., Bird, 1964), the Myall Lakes are separated from the ocean by a large sand mass accumulated around previous islands and headlands. The rock-based sites of previous islands and headlands and present headlands comprise one land system, which is subdivided into two sub-systems according to whether the sites are present headlands or are inland from the contemporary coast. The other three land systems cover the sand mass. One of them comprising Holocene wind-blown sand is not subdivided, but the other two are each divided into sub-systems. The land system comprising land shaped by the action of lake or river waters is divided into three sub-systems; one comprising lake silts and contemporary lake shores, another relict swash-bars and the third, sand masses other than obvious swash-bars away from contemporary lake shores but apparently reworked by river or lake action. The fourth land system comprising Pleistocene sands other than those worked by lake or river is divided into several sub-systems according to the mode of formation and type of land surface produced in the sands.

Mostly boundaries between land systems are clear and were easily recognized. However, at Bridge Hill and Horse Point, some sands that have been assigned to the Holocene sand land system may be Pleistocene in their age. They certainly lie to the north of the ridge of Holocene long-walled transgressive dunes described in Thom, Bowman & Roy (1981), but their vegetation and topographic settings are more characteristic of Holocene than Pleistocene sand surfaces. It was difficult to recognize clear-cut boundaries between the Pleistocene sand and the lake sediments land systems in the area south-east of Neranie Head and to a lesser extent on the peninsula south of Pigeon Point. Within the Pleistocene sand land system the various sub-systems were mostly easily recognized, but between the southern end of Johnsons Hill and Bombah Point the western boundary between the inner parabolic dunes and the differentiated Inner Barrier could not be distinguished clearly and accordingly is somewhat arbitrary in Figure 1.

The Pleistocene sands show generally low relief with the exception of the dune perched on the northern side of the Big Gibber and the largely aeolian complex east of Bombah Point. The Pleistocene deposits include sands of the Inner Barrier of Thom (1965).

The work of Thom (1965), Shepherd (1970), Thom, Bowman & Roy (1981) and Chapman, Geary, Roy & Thom (1982) allows the relative ages and modes of deposition of the Pleistocene sands to be outlined. Probably the earliest deposit was the aeolian dune sheet perched on the northern side of the Big Gibber. This may have been laid down about 500 000 years ago during the period of formation of the "Ancient Dunes" of Benussi (1975) and Clifford &

TABLE 1

Characteristics of Eurunderee land systems

Parent material		Land		Topography	*Soils
type	sub-type	System	sub-system (symbol in Figure 1)		
Rock	—	Rock	(i) Inland (Ri)	Mostly hills with moderate relief	Lithosols and red and yellow podzolics
			(ii) Headland (Rh)	Seaward-facing slopes often steepening at the base into cliffs	Black headland**
Sand	Pleistocene sand	Pleistocene sand	(ii) Perched dune (Ppd)	Aeolian dune with moderately steep slopes perched on northern side of Big Gibber	Podzol
			(ii) Early Inner Barrier (Pu)	Mostly low-lying and periodically waterlogged, but with some freely drained sand-sheets on slopes overlying rock	Humus podzols mainly, but podzols on freely draining sites
			(iii) Inner parabolic dunes (Pip)	Parabolic dunes of subdued relief and gentle slopes with lower sites periodically waterlogged	Catenary sequences of podzols and humus podzols
			(iv) Differentiated Inner Barrier (Pib)	A system of more or less parallel beach ridges of low relief and gentle slopes with intervening swales periodically waterlogged	As above
			(v) Undifferentiated Inner Barrier (Pub)	Mostly low-lying and periodically waterlogged with a very few low rises towards its edges	Mainly humus podzols, but podzols on the freely draining areas

		(vi) Glacial dune complex (Pg)	A complex of dunes of moderate relief and slopes overlying and including parts of the differentiated Inner Barrier	Podzols, but humus podzols in low-lying sites
		(vii) Probable re-exposed surface (?P)	Low-lying complex of low rises and intervening, periodically waterlogged depressions	? Weakly developed podzols and humus podzols.
		(viii) Inter-Barrier lagoon (Pil)	Low-lying with little relief	Humus podzols and some open water with organic muds
Holocene sand	Holocene sand (Outer Barrier)	— (H)	Transgressive dunes, stabilized except near beach, of considerable relief (up to nearly 100m), frequently with steep slopes, freely draining except for a very few sites.	Weakly developed podzols
Lake-influenced sediments	Lake-influenced sediments	(i) Lake silts and current lake shores (Ls)	Mostly at or below water level, but with some sandy beaches	Mostly organic muds, but also some wave-washed sands.
		(ii) Relict sand-bars (Lb)	Old swash-bars of low relief and very gentle slopes	? Podzols and humus podzols
		(iii) Sand of probable fluvial (and lacustrine) origin (Li)	Sand sheets of moderate to low relief with generally gentle but with some localized moderately steep slopes.	Podzol

*Soil terminology based on Stace *et al.* (1968); **Soil type of Parbery (1947) — see also Corbett (1972)

Specht (1979) on North Stradbroke Island and similarly aged dunes on other dune islands off south-eastern Queensland. This dune sheet on the Big Gibber had a giant podzol similar to those described on the "Ancient Dunes" of North Stradbroke Island by Thompson & Ward (1975) and Clifford & Specht (1979). Unfortunately it was largely destroyed in recent sand-mining operations. Other Pleistocene sands were probably laid down much later, though it is not possible to suggest a date for deposition of sands on the peninsula south of Pigeon Point and southeast of Neranie Head and south of Smiths Lake, which have been assigned to the early Inner Barrier sub-system. In terms of the chronology given in Chapman *et al.* (1982), the inner parabolic dunes were probably deposited about 125 000 years ago during the highest sea level reached during the Last Interglacial period. These were followed by the beach ridges of the differentiated Inner Barrier. The area of undifferentiated Inner Barrier between Kataway Bay and the Big Gibber was probably formed as a back-wash lagoon or saltmarsh behind the inner parabolic dunes and beach ridges. It is fringed on its northern, western and southern edges by remnants of low ridges that could have formed by wave action in a lagoon or across a saltmarsh flooded at high tides. For brevity, this area is hereafter referred to as the Eastern Lagoon. The aeolian complex east of Bombah Point was, according to Thom, Bowman & Roy (1981), probably deposited during a period between 20 000 and 12 000 years ago under the influence of strong westerly winds in the Last Glacial period.

The Holocene sand comprising the Outer Barrier is discussed by Thom (1965), Thom *et al.* (1978) and Thom, Bowman & Roy (1981) and is taken by Chapman *et al.* (1982) as a prime example on the New South Wales coast of an episodic transgressive dune barrier. It consists of high and often steeply sloping transgressive dunes, contrasting sharply with the generally low and gently undulating Pleistocene surfaces. The Holocene surfaces date from various episodes of dune-building but mostly are not older than the stillstand in the rise in sea level about 6 500 years ago (see Thom *et al.*, 1978; and Thom, Bowman & Roy, 1981). The possible factors operating during the episodes of formation of these dunes are discussed by Thom (1978), Thom *et al.* (1978) and Chapman *et al.* (1982).

Lake-sand swash-bars occur at heads of bays on the lakes where they abut sand masses. Shepherd (1970) refers those furthermost from the present lake shores to the Pleistocene. In addition, on the peninsula south of Pigeon Point and near the junction of Boolambayte Lake and Bombah Broadwater, there are sand masses apparently deposited following lake or river action.

Some areas that could be outliers of one system or sub-system within another are not shown in Figure 1 on account of their small size but a few of them will be mentioned in the interpretation of the vegetation.

The sands are siliceous, including those of the dunes immediately behind the beaches, and consequently their soils are podzols whose stage of development and type depend on the age and hydrology of the surface (Table 1). In this respect the recent dunes are typical of those of New South Wales and are similar to those of southern Queensland rather than to most of those of South Australia (Coaldrake, 1982; Chapman *et al.*, 1982).

VEGETATION

The preliminary survey of the area's vegetation by Osborn & Robertson (1939) was conducted in almost inaccessible country, when standard vertical aerial photographs were unavailable. It is therefore understandable that they did not distinguish some of the communities recognized here, that they oversimplified the definitions and distributional patterns of communities, and that they did not adequately locate some observations. Little has been published since this survey, although recently the aquatic communities of the lakes have been described (Atkinson *et al.*, 1981). Unpublished work has included a statement by Carolin for the Linnean Society of New South Wales on the scientific importance of the area, lists of species within mining dredge-paths by Clarke, a report by Pickard & Blaxell for the National Parks and Wildlife Service of New South Wales on the vegetation, a report on a heathland investigation from Macquarie University, and a description and map of the vegetation of northern parts of the area by Anderson (1973). Though the treatment of the vegetation given below is similar to Anderson's (1973), there are two main differences. Firstly, only communities are recognized here, while Anderson (1973) distinguishes associations within communities. Secondly, in freely-drained forests a distinction is made between those on Holocene and those on Pleistocene sands, a distinction that Anderson (1973) does not make.

The term community was used instead of association for the classes of vegetation recognized here for two reasons. Firstly, a strict definition of association, as a "climax community of which the dominant stratum has a qualitatively uniform floristic composition, and which exhibits a uniform structure as a whole" (Beadle & Costin, 1952), was difficult to apply to the area's vegetation. As will be shown, there are situations where uniformity of structure is not preserved either in height or in cover of the canopy, but uniformity of floristic composition is. It was the relative uniformity of floristic composition that was the overriding consideration in the recognition of the communities described below. Secondly, the width of definition of communities recognized varied somewhat with the type of parent material on which the vegetation studied was growing. Communities on rock-based sites were more widely defined than those growing on sand, largely because the interest of the study was centred on the vegetation of the sand masses. However, the term community used here is roughly equivalent to that of association in Beadle (1981).

The present vegetation on some sites is secondary following human disturbance. Many of the inland rock-based sites were logged and cleared for grazing following European settlement. More recently, some sand-based areas have been mined. Four areas were so mined: one strip mostly in Pleistocene inner parabolic dunes west of the southern part of Johnsons Hill toward Bombah Point; another including most of the area of the Pleistocene perched dune on the northern side of the Big Gibber and extending southwest through the Holocene sands of the Outer Barrier for about five kilometres; another strip, approximately 2.5 kilometres long, west of Yagon Gibber through Holocene and re-exposed Pleistocene sands at the back of Submarine Beach; and the fourth area in the Bridge Hill ridge of the high Holocene dunes east of the Seal Rocks road. In all such disturbed sites the vegetation has been described in this survey either in its known or in its putative undisturbed state.

Community recognition

The communities recognized are listed with their structural forms under Specht's (1970) terminology in Table 2. Using floristic criteria in community recognition and definition, certain communities cover a wide range of structural types. For instance, Dry Heath sometimes contains shrubby specimens of *Eucalyptus gummifera* and *E. pilularis* but is structurally quite different from Dry Heath Forest. It was, therefore, decided that very broad structural criteria should be used with floristic criteria to recognize and define the communities. Names given to some of these communities come from the terminology of Beadle & Costin (1952) but are used here in a local restricted sense. Names given to the others were invented during the course of this study to indicate the dominant growth-forms and habitats of the communities. The exceptions to this are Dry Heath Forest, Wet Heath Forest and Intermediate Dry Forest. These were named on their similarity to other communities: Dry Heath Forest to Dry Heath; Wet Heath Forest to Wet Heath; and Intermediate Dry Forest on its position intermediate in floristic similarity between Dry Sclerophyll Forest and Dry Heath Forest. Heath forest was used by Richards (1936) for relatively sclerophyllous tropical forest growing on infertile soils, and was his translation

TABLE 2

Eurunderee plant communities, their structural forms and habitats

Dominant growth-form	Community (abbreviation)	Structural form (of Specht, 1970)	Habitat
Trees	Rainforest (RF)	Closed-forest	One rock-based site near Seal Rocks
	Wet Sclerophyll Forest (WSF)	Tall open-forest, Open-forest	Freely drained, rock-based sites not exposed to the sea
	Dry Sclerophyll Forest (DSF)	Tall open-forest, Open-forest, rarely Open-scrub	Freely drained sands, excepting the seaward front of dunes, usually with only weakly developed podzols or close to rock
	Intermediate Dry Forest (IDF)	Open-forest	Freely drained sands probably of intermediate stages of podzol development
	Dry Heath Forest (DHF)	Open-forest, Low open-forest, Woodland, Low woodland	Freely drained sands with well developed podzols
	Wet Heath Forest (WHF)	Open-forest	Sands close to but nearly always above the water-table
	Swamp Forest (SF)	Open-forest, Low open-forest, Woodland	Sands periodically submerged and nearly always waterlogged
	Fringe Forest (FF)	Open-forest	Lake margins irrespective of substrate—rock, sand or organic sediment
Small trees	Headland Thicket (HT)	Low closed-forest, Low open-forest, Closed-scrub, Open-scrub, Closed-grassland	Rock-based headlands facing the sea
	Vine Thicket (VT)	Low closed-forest, more commonly Closed-scrub	A moist protected rock-based gully facing the sea near Seal Rocks

	Beach-dune Thicket (BT)	Low open-forest, Closed-scrub, Open-scrub	Freely drained sands in stabilized transgressive dunes immediately behind the beach-front
Shrubs	Dry Heath (DH)	Closed-heath, less commonly Open-heath	Freely drained sands with well developed podzols
	Wet Heath (WH)	Closed-heath, less commonly Open-heath	Sands close to but nearly always above the water-table with well developed humus podzols
Herbs	Sand Grassland (SG)	Closed-grassland, Grassland	Freely drained stabilized sand on steep slopes facing the sea between Seal Rocks and Smiths Lake
	Foredune Complex (FC)	Grassland, Open-grassland, Herbfield, Open-herbfield	Mobile and semi-stabilized sands of beach-fronts and blow-outs
	Swamp (S)	Sedgeland, less commonly Open-heath, Open-scrub	Sands periodically submerged amd nearly always waterlogged
	Lepironia Swamp (LS)	Sedgeland, Open-sedgeland	Apparently fairly recently formed areas of open water on sands

of Winkler's (1914) term, *Heidewald*, for these forests. Such heath forests occur widely in the moist tropics (Richards, 1952; Whitmore, 1975; Specht, 1979*a*), and are the characteristic vegetation on lowland podzols which in Eastern Asia are most widespread on old beach deposits (Burnham, 1975).

Recognition of some communities required no detailed analysis, but the six communities outlined in Figure 2 did. Five of the communities, Dry Heath Forest, Dry Heath, Wet Heath, Swamp Forest and Swamp, occur in catenary sequences particularly in the differentiated Inner Barrier. Lack of obvious boundaries between communities in these catenary sequences makes recognition and definition of these five communities difficult. Also, it was not immediately apparent to what extent Dry Heath, which occurs extensively on Pleistocene sands, and Dry Sclerophyll Forest, which occurs predominantly on Holocene sands, were floristically similar despite their difference in structure. Accordingly, a transect, almost 4 km long, was laid out northwest to southeast, from between Johnsons Hill and Tickerabit to the coast, traversing the inner parabolic dunes, differentiated Inner Barrier, inter-Barrier lagoon and Outer Barrier (see map located in back pocket). A method of scoring the occurrences of species was chosen which over such a long transect was not too time consuming. The size of sample units was selected such that it would detect groupings in the occurrences of species at a scale that was appreciably smaller than the average length of each catenary sequence in the pattern of variation of vegetation over the system of ridges and swales of the differentiated Inner Barrier, and yet not so small that fine-scale groupings of species within localized segments of the catenary sequences could predominate over more general groupings. A point quadrat was used at 1 m intervals. For each species the hits from the point quadrats were blocked into 10 m units and these units used in the analysis for the detection of groupings in the occurrences of species. Ridges occur at a frequency of approximately five per kilometre across the differentiated Inner Barrier making the approximate average length of a catenary sequence from the top of a ridge to the lowest point of a swale 100 m. The sampling units (10 m long) are thus an order of magnitude shorter than the average length of a catenary sequence.

In the analysis of data, groupings were sought in the occurrences of the species by calculating from the hit data the degree of association between species taken a pair at a time for all pairs of species encountered. Multivariate methods of classification or ordination of the 10 m blocks of point quadrats could only indirectly show floristic groups in the occurrences of the species. Williams (1968) used such methods on data collected from 1 m^2 quadrats positioned by restricted randomization in each of 12 parallel transects across part of the differentiated Inner Barrier. His investigation assisted in interpreting the occurrences of species relative to local environmental variation, but was not particularly helpful in recognizing communities according to groupings in the occurrences of species.

The choice of a coefficient of association between species in pairs presented some problems. Since the data in each 10 m length could be expressed as estimates of cover for the species encountered it would appear possible to use Pearson's Product Moment correlation coefficient (r). However, the domain from which the data were drawn was so wide in the case of every pair of species that the number of joint non-occurrences exceeded the joint occurrences together with the single occurrences of each species. Thus, the distribution of estimates of cover in each species is not normal. The use of r was accordingly ruled out.

The data can be taken in a simplified form in which the requirements of normal distributions do not arise and where other coefficients of association are available. This is done by taking the data in binary form, recording for each species whether or not its aerial parts intersected any of the ten pins in each

10 m length of the transect. Coefficients of association available for use with binary data include the tetrachoric correlation coefficient (phi) (see Sokal & Sneath, 1963), the χ^2 coefficient of heterogeneity (Greig-Smith, 1964) and the simple matching coefficient of Sokal & Sneath (1963). However, the high numbers of joint non-occurrences in the set of data ensure that none of these coefficients is a satisfactory estimate of joint occurrence. Moreover, the χ^2 coefficient is a test of significance not of association (see Hubálek, 1982). The Jaccard coefficient was also rejected because association of a very frequent species with a relatively infrequent species in a pair will show low values of the coefficient even when the latter species only occurs with the former and never by itself.

The sort of coefficient of association required is one whose values are not dependent on the joint non-occurrences of the species in a pair and sensitively reflect the joint occurrences with respect to the less frequent of the species. Such a coefficient is available. The data take the following form:

		sp. J	
		−	+
sp. K	−	n_{jk}	n_{Jk}
	+	n_{jK}	n_{JK}

where: − is non-occurrence of a species;
+ is occurrence of a species;
n_{jk} is the number of sites in which neither species occurs;
n_{Jk} and n_{jK} are each the number of sites in which species J or species K respectively occur without the other species; and
n_{JK} is the number of sites in which the two species jointly occur.

The coefficient of association in question is:

$$\frac{n_{JK}}{\min\left[(n_{Jk} + n_{JK}), (n_{jK} + n_{JK})\right]}$$

and seems to have been first used as the "degree of faunal resemblance" by Simpson (see Hubálek, 1982, who refers to it as "A_2"). This coefficient varies in value between zero and one, takes no regard of joint non-occurrences and expresses the joint occurrence with respect to the less frequently occurring species.

Hubálek (1982) rejects this coefficient because it is asymmetric (admissibility condition 3) although he does concede that it may have a use in measuring partial or one-way associations, and this is just what is needed in this case. Furthermore it does not satisfy an "additional (optional) condition" of absolute association that he considers. This again is satisfactory in this case since the less frequent species needs to control the coefficient.

Values of this coefficient of association can be calculated between all pairs of species sampled, and values over a selected minimum can be used to express association in linked clusters. Figure 2 shows the linked clusters in the pair-wise associations in occurrences of the species along the transect when all values of the coefficient of association of 0.50 and over have been plotted. It is not clear that a satisfactory test of the statistical significance of these values is available. The minimum of 0.50 gave, in this set of data, a workable number

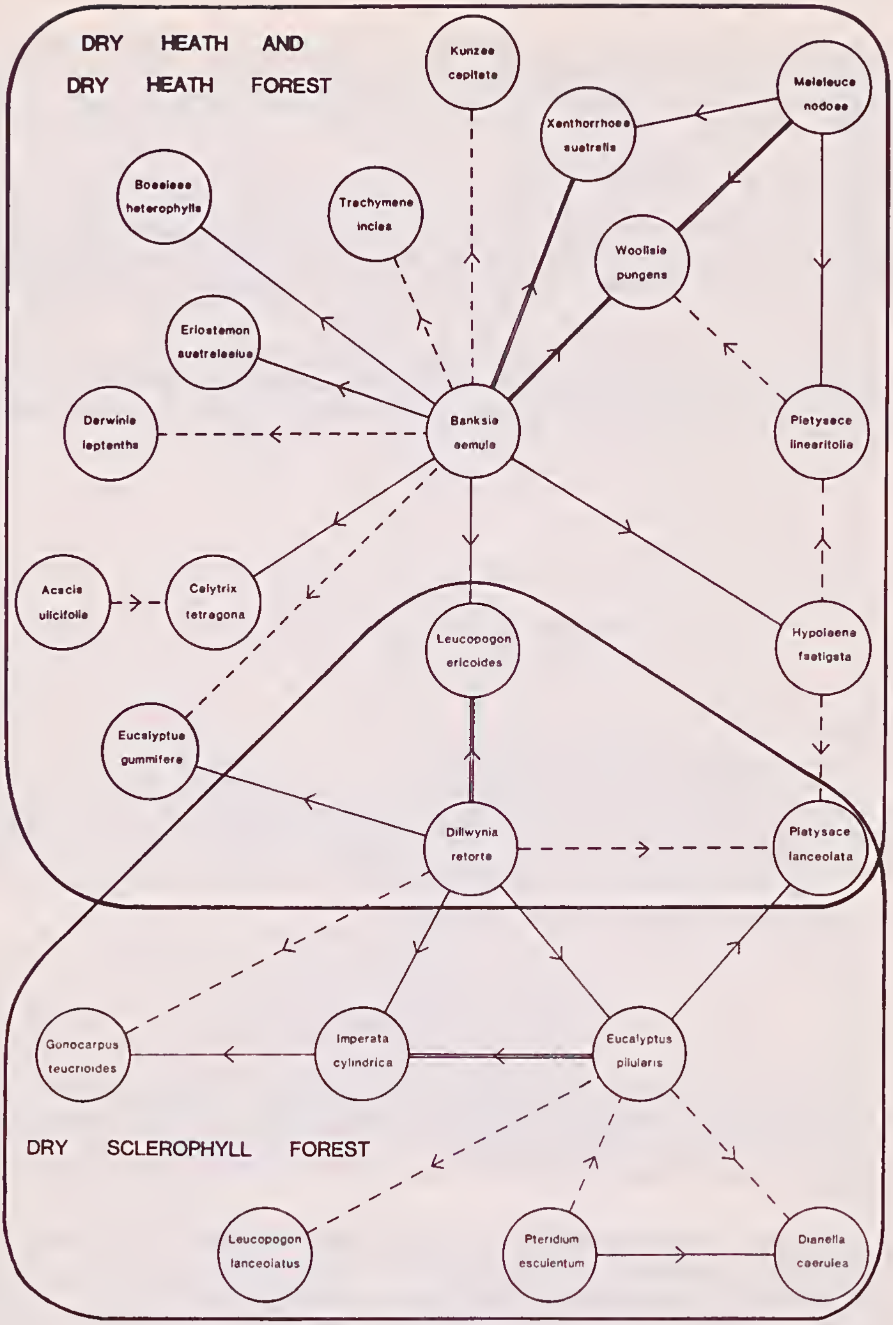
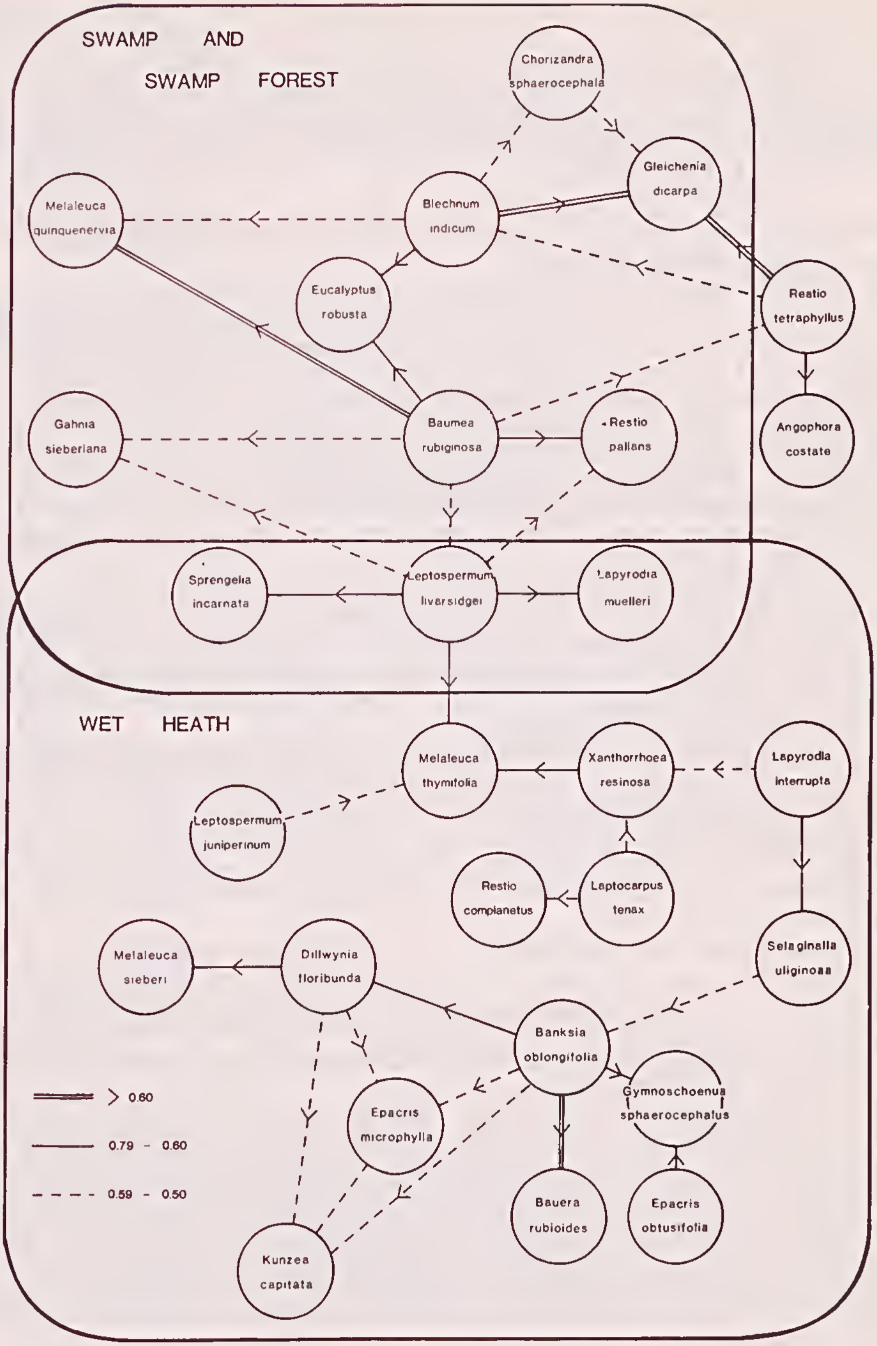


Figure 2. Summary of pair-wise associations of species in their occurrence in successive 10 m lengths along a transect taken south-east from between Johnsons Hill and Tickerabit across the inner parabolic dunes (Pip), differentiated Inner Barrier (Pib), inter-Barrier lagoon (Pil) and the Outer Barrier (H) to the sea (for approximate location of transect see map located in back pocket). An occurrence was recorded as intersection of aerial plant parts with one or more of 10 point quadrats one of which was placed at each successive metre along the 10 m length. All values of a coefficient



of association greater than 0.50 are plotted (see text for definition of the coefficient). For each pair-wise association of species shown, the species with the greater frequency of recorded occurrence on the transect is indicated by the appropriate sign (>, or = when frequencies of both spp. were equal) on the line signifying their association. The bold lines enclose clusters of species deemed to belong to particular plant communities.

of species and linkages to plot. At a minimum of 0.40, the numbers of species to be considered and of the linkages between them are too high for a plot that can be easily shown in a diagram or readily interpreted. The clusters in Figure 2 are meaningful biologically and indicate floristic groups of species on the ground as well as widely spread species whose occurrences overlap into various groupings of less widespread species. In this way, the clusters approximate to the "noda" of Poore (1964).

The floristic groupings shown in Figure 2 are related to the catenary sequences of vegetational change across the differentiated Inner Barrier and to age of freely drained surfaces.

The cluster of species comprising Swamp and Swamp Forest characterizes wet sites in the swales. As explained later, Swamp is differentiated from Swamp Forest largely by absence of trees from the former and not by any major floristic difference in the understorey. The two species of trees of Swamp Forest, *Melaleuca quinquenervia* and *Eucalyptus robusta*, occur within the cluster and *Angophora costata* is associated with it through *Restio tetraphyllus*. Neither *R. tetraphyllus* nor *A. costata* occurs in the bottoms or on the lower slopes of swales. *A. costata* occurs on freely drained sands but its occurrence extends on to surfaces closer to the water-table than those on which *Eucalyptus pilularis* and *E. gummifera* occur, the other main species of trees on freely drained sands in this transect.

The shrubs *Leptospermum liversidgei* and *Sprengelia incarnata*, and the restiad *Lepyrodia muelleri* are included in both the cluster of species comprising Swamp and Swamp Forest and the cluster of species comprising Wet Heath. The three species occur in the differentiated Inner Barrier on the lower slopes of swales where Swamp and Swamp Forest merge into Wet Heath in the catenary sequence of vegetation.

A somewhat loosely linked cluster of species of mostly shrubs and restiads comprises Wet Heath, the community characteristic of the slopes of the swales in the differentiated Inner Barrier. In this, *Banksia oblongifolia* is a prominent and physiognomically obvious species. *Kunzea capitata* occurs on the upper slopes of the swales and has been included both in the cluster of species comprising Wet Heath and in the cluster designated Dry Heath and Dry Heath Forest.

Dry Heath and Dry Heath Forest in this analysis are composed of a large cluster of species, most of which are shrubs, that occur on the ridges of the differentiated Inner Barrier. As explained later, the two communities are largely separated physiognomically on the presence or absence of trees. The cluster is centred on *Banksia aemula*, a prominent and characteristic species of these two closely related communities.

Finally, the cluster of species designated Dry Sclerophyll Forest, and including the relatively close association of *Eucalyptus pilularis* and *Imperata cylindrica*, is characteristic of forested, freely draining Holocene sands of the Outer Barrier. The species of this cluster all occur in Dry Heath Forest on Pleistocene sand but with much lower abundances than those they have on Holocene sands. *Leucopogon ericoides, Dillwynia retorta* and *Platysace lanceolata* occur with appreciable abundance in both Dry Heath Forest/Dry Heath and Dry Sclerophyll Forest and are accordingly included in each of these respective clusters.

Other communities described were fairly readily differentiated by floristic and physiognomic characteristics. One community, closely related to Wet Heath and to Swamp Forest and termed Wet Heath Forest, was recognized during the course of mapping the vegetation following the diagnosis of communities outlined by the floristic clusters in Figure 2. It consists of trees of *Melaleuca quinquenervia, Eucalyptus robusta* and *Angophora costata* with an understorey that is a mixture of Wet Heath and Swamp species. It mostly occurs on sheltered

Pleistocene sands where water is often close to the surface and which may receive run-off from nearby rock-based sites.

The map located in the back pocket shows the distribution of the communities outlined in Table 2 and described below in more detail. Subtropical Rainforest in a small area near Seal Rocks and much disturbed by human activity is mapped but not described here; it was studied and described by Clough (1979).

Community comparisons

The floristic compositions of all the communities were compared except for localized or rare communities, namely Rainforest, Vine Thicket, Sand Grassland and *Lepironia* Swamp. Data for the comparison were gathered from six sites in each community. In each community the sites were chosen to cover its full range within the study area in the geographic sense, in the range of habitats occupied and in the structural variation the community showed. At each site the area sampled was selected because it was representative of the middle of the range of variation of the structure of the community and floristic composition of the physiognomically most obvious species at the site. The range of variation of structure and composition was determined by preliminary visual assessment. Possible ecotones were avoided, and in each site all species of vascular plants occurring in each of nine quadrat units laid contiguously in a transect were recorded. A quadrat unit of 5 × 5 m was used for herbs and shrubs up to 3 m high, and a unit of 10 × 10 m for trees and shrubs over 3 m high. The transect sampled in each site thus consisted of a belt of nine 5 × 5 m quadrats from 0 to 45 m and a belt of nine 10 × 10 m quadrats from 0 to 90 m, the second belt of quadrats being superimposed on the first over the distance 0 to 45 m. The frequency of each of the 369 species recorded was calculated in each community and the communities were initially compared using the Canberra metric,

$$\text{Canb} = \frac{\sum\limits_{j=1\to369} |x_{ij} - x_{kj}|}{\sum\limits_{j=1\to369} x_{ij} + x_{kj}}$$

where x_{ij} is the frequency of the jth species in the ith community; and

x_{kj} is the frequency of the jth species in the kth community.

The Canberra metric is thus inversely related to similarity.

The Canberra metric was selected since the full matrix of frequencies of species in the communities could be examined, and a value of the metric would be assigned in each comparison between two communites in relation to the total number of species encountered. Only by use of such a metric could values between pairs of communities be directly inter-related. Indices of comparison such as Jaccard's or Czekanowski's coefficients (see Greig-Smith, 1964), whose values are determined solely by the pairs of samples being compared without reference to the total set of samples, do not yield values between pairs that can be directly compared across all the samples taken. The Canberra metric (see Clifford & Williams, 1976) is of the type required and is mathematically simple.

Values of the Canberra metric range between zero, for a pair of identical samples, and one, for a pair of totally dissimilar samples. To compare the communities here, it was decided that a value of the metric between two communities of 0.8 or more would be taken to indicate a lack of similarity between two such communities.

From the values of the Canberra metric obtained (Table 3) and using only those less than 0.8, the communities are seen to be interconnected in a sequence of similarities (Figure 3). In the sequence, wetland communities are at one end

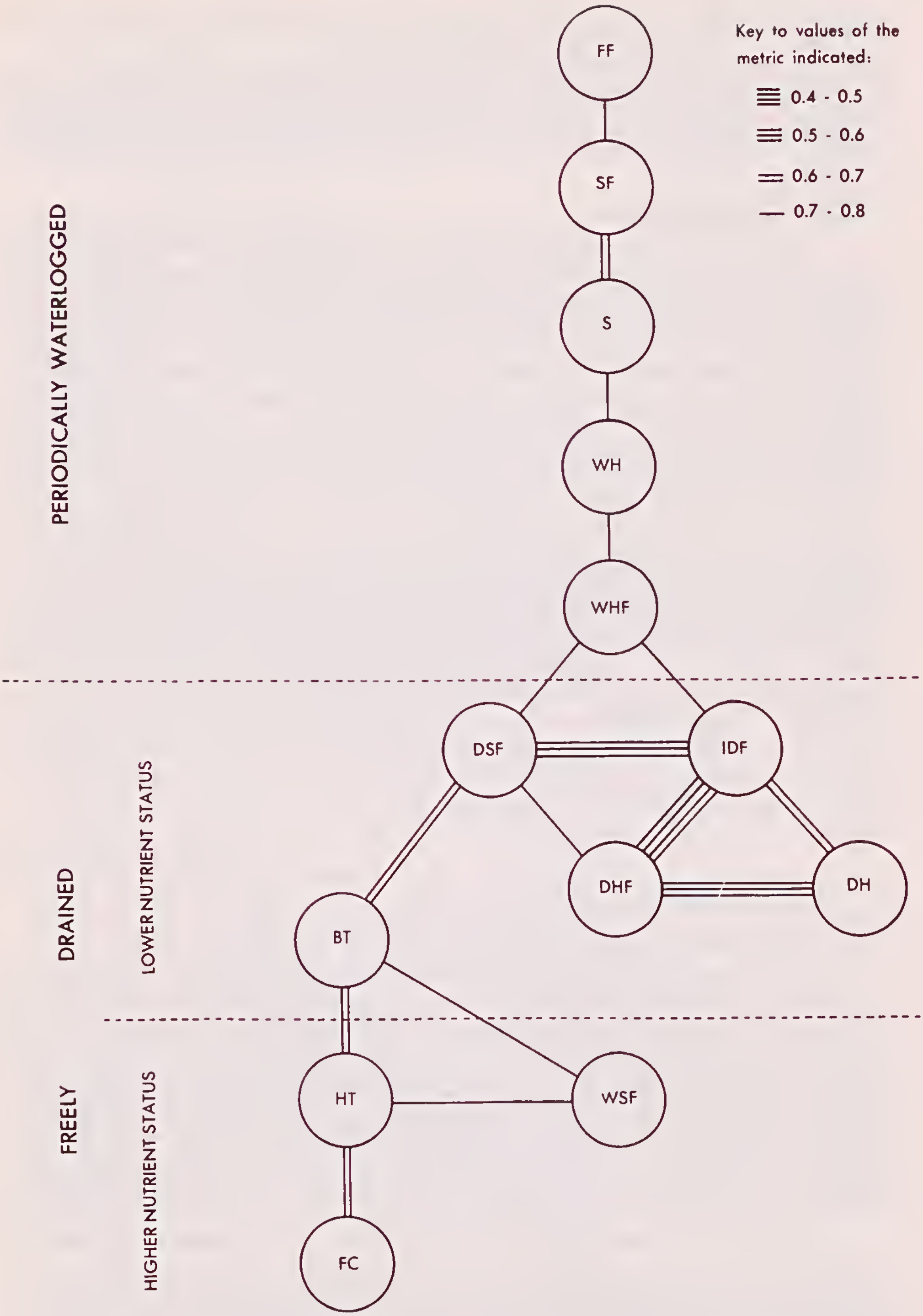


Figure 3. Comparison of communities using values of the Canberra metric less than 0.8. It should be noted that the lower the value of this metric the greater the similarity between communities. (For full names of the communities see Table 2).

and communities of dry land at the other end. Within the communities of dry land there are groups that can be related to differences in probable nutritional status. Communities that are probably of relatively high nutritional status (Foredune Complex, Headland Thicket and Wet Sclerophyll Forest) are grouped loosely together and those probably of low nutrient status (Dry Heath, Dry Heath Forest, Intermediate Dry Forest and Dry Sclerophyll Forest) are more closely grouped. Beachdune Thicket connects the two groups. Such a nutritional interpretation is supported by the ages and degree of podzolization of the surfaces on which the communities characteristically occur. The Foredune Complex and Beach-dune Thicket, which occur on recently deposited surfaces, are at one end and Dry Heath and Dry Heath Forest, which occur on highly podzolized Pleistocene surfaces, at the other of this sequence of communities from freely draining sands.

Comparison of sand-based communities

Nine of the 12 sand-based communities were compared in greater detail. The three omitted were the highly localized Sand Grassland and *Lepironia* Swamp and the continuously disturbed Foredune Complex.

The six sites sampled in each community were treated individually. Patterns in the floristic relationships of the 54 sites were explored through Principal Coordinate Analysis in the GOWER and GOWERCOR programs from the CSIRO TAXON package (see Milne, 1976), using Euclidean chord distance, which is sensitive to differences in proportions of species' frequencies rather than to differences in the frequency values themselves (Orlóci, 1967; 1975).

The first two axes extracted in the analysis (Figure 4) have a discernible relation to the environmental variation. The first axis appears to reflect mainly drainage, with sites of the periodically waterlogged communities registering positive and those of the freely draining communities negative values. Clearly the axis does not reflect the degree of waterlogging in a simple way since Wet Heath sites are more strongly positive than most of the Swamp Forest sites. The second axis appears to reflect age of the surfaces; the younger sites registering positive and the older negative values. This tendency is clear-cut in the freely drained sites where the stands of Intermediate Dry Forest, which are particularly typical of late Pleistocene sites, occupy a position between the stands of Dry Heath and Dry Heath Forest, which occur predominantly on earlier Pleistocene sands, and those of Dry Sclerophyll Forest, characteristic of Holocene sands. The waterlogged sites are not well spread on the axis. This result is perhaps hardly suprising since they are all from Pleistocene sands. However, some of the sites giving the most positive values included in the spread of Wet Heath Forest occur near the base of rock hills from which some run-off of nutrients might be expected, suggesting again that the age sequence apparent in the freely draining communities may be related to variations in nutrient status.

Community descriptions

Communities are described in the sequence in which they are listed in Table 2. Communities on the sand masses are the primary interest of this paper and are described in greater detail than those on the rock-based soils.

The codes of Pryor & Johnson (1971) for species of *Eucalyptus* and *Angophora* are given at the first mention of the name of any eucalypt or angophora species in the description of community. This is to allow ready assessment of the affinities of eucalypt species occurring together in the same community.

Nomenclature of species generally follows that of Jacobs & Pickard (1981), and authorities are only given for the specific names which are not those in Jacobs & Pickard.

TABLE 3

Values of Canberra metric (an index of dissimilarity) from the floristic comparison of the commoner Eurunderee plant communities

Community*	WSF	DSF	IDF	DHF	WHF	SF	FF	HT	BT	DH	WH	FC	S
WSF	0												
DSF	0.875	0											
IDF	0.907	0.567	0										
DHF	0.968	0.729	0.454	0									
WHF	0.834	0.758	0.750	0.862	0								
SF	0.963	0.959	0.983	0.935	0.823	0							
FF	0.928	0.988	0.991	0.992	0.940	0.783	0						
HF	0.782	0.818	0.854	0.904	0.831	0.951	0.933	0					
BT	0.792	0.695	0.805	0.899	0.831	0.944	0.966	0.622	0				
DH	0.989	0.839	0.655	0.598	0.825	0.978	0.995	0.936	0.924	0			
WH	0.998	0.961	0.927	0.943	0.703	0.868	0.981	0.976	0.940	0.874	0		
FC	0.930	0.954	0.975	0.976	0.970	0.973	0.955	0.695	0.867	0.991	0.989	0	
S	1	0.916	0.973	0.956	0.915	0.635	0.894	0.982	0.985	0.954	0.740	0.998	0

* Full names of communities are given in Table 2.

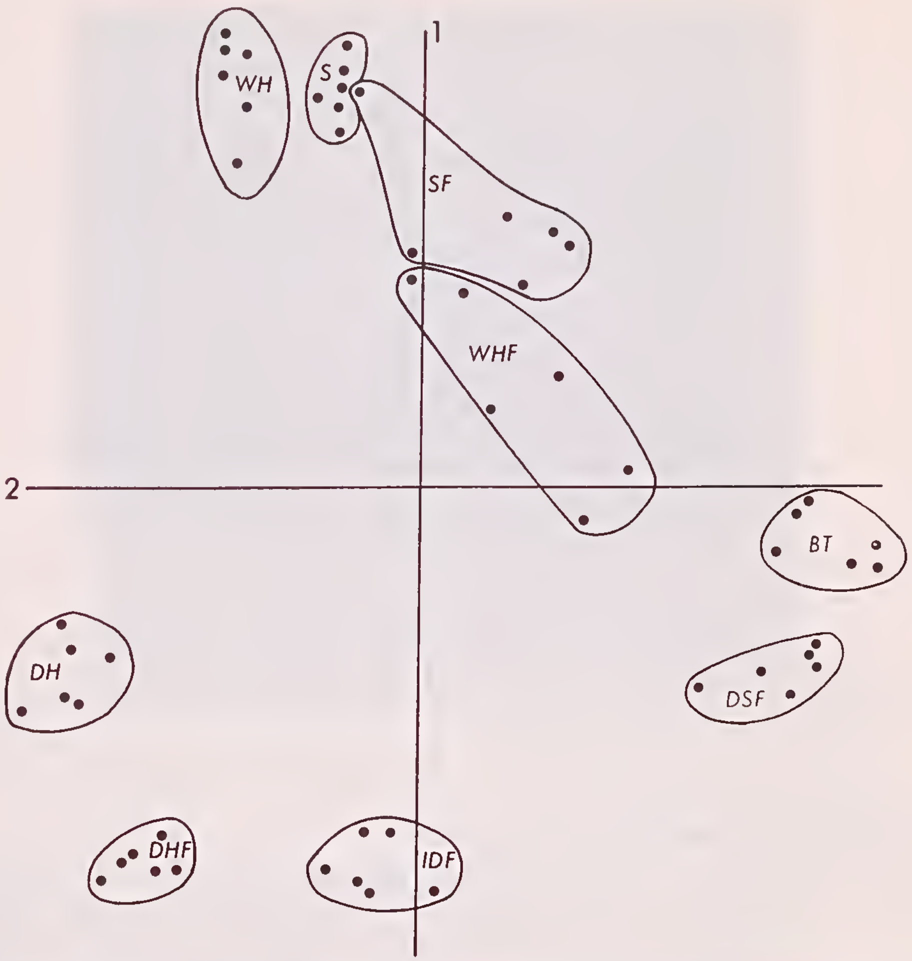


Figure 4. Ordination of stands of nine common sand-based communities on the first two axes extracted in a principal co-ordinate analysis. (For full names of communities see Table 2).

WET SCLEROPHYLL FOREST (Figure 5)

Tree stratum (to c. 35 m): e.g., AAABB *Angophora floribunda*, CCC:B *Eucalyptus maculata*, SWA:A *Eucalyptus microcorys*, SUV:D *Eucalyptus paniculata*, *Syncarpia glomulifera*.

Small tree stratum (to c. 15 m): e.g., *Casuarina torulosa*, *C. littoralis*, *Melaleuca styphelioides*, *Lophostemon confertus* (R.Br.) Peter G. Wilson & J. T. Waterhouse (=*Tristania conferta*).

Shrub stratum (to c. 1.5 m): e.g., *Oxylobium ilicifolium*, *Daviesia ulicifolia*.

Soils: lithosols, red and yellow podzolics.

This community occurs on the rock-based soils of prior islands and headlands, but it has been very largely altered by man's activities, including complete clearing of extensive areas. Recent regeneration in cleared areas from which stock have been excluded consists largely of *Acacia parramattensis* and

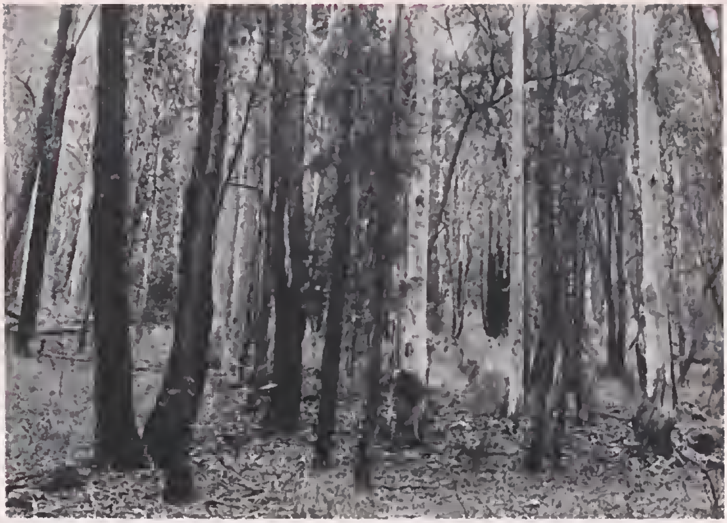


Figure 5. Wet Sclerophyll Forest on eastern slopes of Johnsons Hill. *Eucalyptus paniculata, E. punctata, E. maculata* and *Acacia longifolia* (regrowth following clearing).

Casuarina spp., but on Tickerabit much of the woody regeneration at considerable distances up the slope from the lake consists of *Casuarina glauca* and *Melaleuca quinquenervia,* which are confined to the lake fringes in uncleared but otherwise similar situations.

The community includes all but the sandier facies of Anderson's (1973) fl layered forest association.

DRY SCLEROPHYLL FOREST (Figure 6)

Tree stratum (to c. 40 m): MAIAA *Eucalyptus pilularis* and AAADAA *Angophora costata.* Many over-mature to dead trees of the former; rarely CAFUF *Eucalyptus gummifera* towards the northeastern parts; very rarely SWA:A *E. microcorys,* probably when rock is near the surface.

Small tree stratum (to c. 15 m): *Banksia serrata, Xylomelum pyriforme,* and *Monotoca elliptica,* with *Casuarina torulosa* when rock is near the surface. Saplings and young trees of tree stratum.

Shrub stratum (to 3 m): *Aotus ericoides, Dillwynia retorta, Gompholobium latifolium* and *G. grandiflorum, Leucopogon lanceolatus,* and very many others depending on the fire history of area. *Xanthorrhoea australis* and *Macrozamia communis* are locally common.

"Herb" stratum: *Pteridium esculentum* (Forst.f.) Cockayne, *Imperata cylindrica, Panicum simile, Gonocarpus teucrioides* and many others, probably depending on the recent fire history of the area.

Soils: poorly developed podzols, with humus-stained A_1, bleached A_2 horizon, and B horizon sometimes distinct but usually poorly developed or lacking.

In this forest on Holocene sand, dominated by *Angophora costata* and *Eucalyptus pilularis,* there are many over-mature and standing dead trees of *E. pilularis* despite extensive logging operations. In contrast, there are few standing dead trees of *A. costata*; its dead timber seems to degrade much faster than that

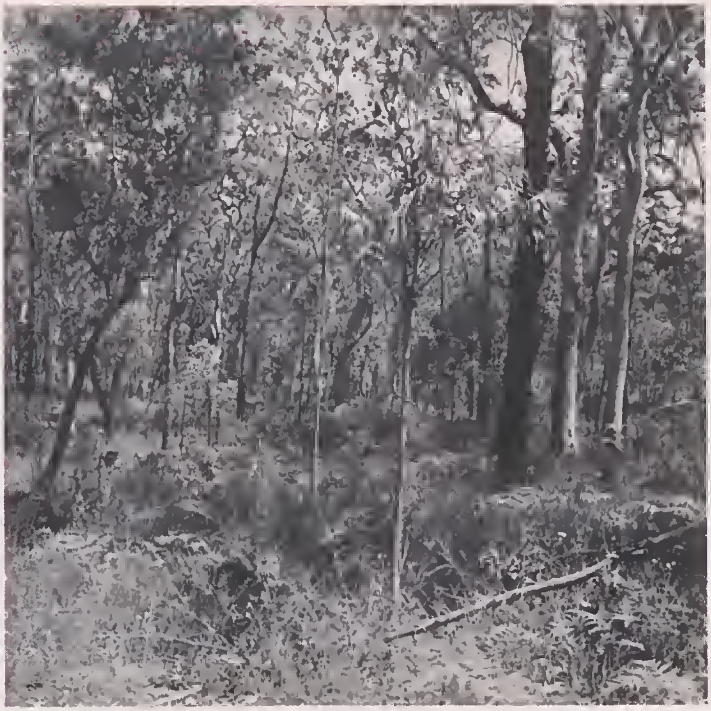


Figure 6. Dry Sclerophyll Forest on Holocene dunes about 1 km south of Bridge Hill. *Angophora costata* and *Eucalyptus pilularis, Banksia serrata* with *Macrozamia communis, Pteridium esculentum.*

of *E. pilularis.* Data of Fox, Fox & McKay (1979) indicate that after about 10 years following fire the amount of litter on the forest floor reaches a steady-state average of about 1.7 kg m^{-2}, with a turn-over time of somewhat over three years. Evidence of firing is extensive, and charcoal layers, exposed some distance below the surface during sand-mining operations, indicated that fires, at times fierce, have been a feature of the vegetation of these dunes for some time. Indeed, Thom *et al.* (1978) give a C^{14} date of 2 320 ±110 years B.P. for one of these charcoal-rich zones.

The tree stratum varies from pure *Angophora costata* through mixed stands to pure *Eucalyptus pilularis.*

Northeast of the Bungwahl–Seal Rocks road occasional *Eucalyptus microcorys,* and more frequent groups of *Casuarina torulosa* probably indicate rock at no great depth below the sand. The occurrence of *Eucalyptus gummifera* in the same area was more puzzling since it was not associated with rock near the surface (a mining track has now removed it). Here, Anderson (1973) assigns *E. gummifera* to a distinct association, the Bloodwood–*Angophora costata* association, in her layered forest community. Elsewhere, *E. gummifera* occurs in Dry Sclerophyll Forest only where Holocene sand thinly overlies Pleistocene sand or rock. Otherwise, on the sand mass it is confined to Dry Heath Forest and Dry Heath.

Dry Sclerophyll Forest without *Eucalyptus gummifera* is equivalent to Anderson's (1973) Blackbutt–*Angophora costata* association, but, as mapped by her, this association includes patches of our Dry Heath Forest. Dry Sclerophyll Forest also covers the sandier facies of Anderson's (1973) fl layer forest association, which includes *Casuarina torulosa,* but mostly this association lies within Wet Sclerophyll Forest.

Dry Sclerophyll Forest varies somewhat in form, most likely due to exposure and fires. A scrub of *Eucalyptus pilularis,* almost a pure stand, with

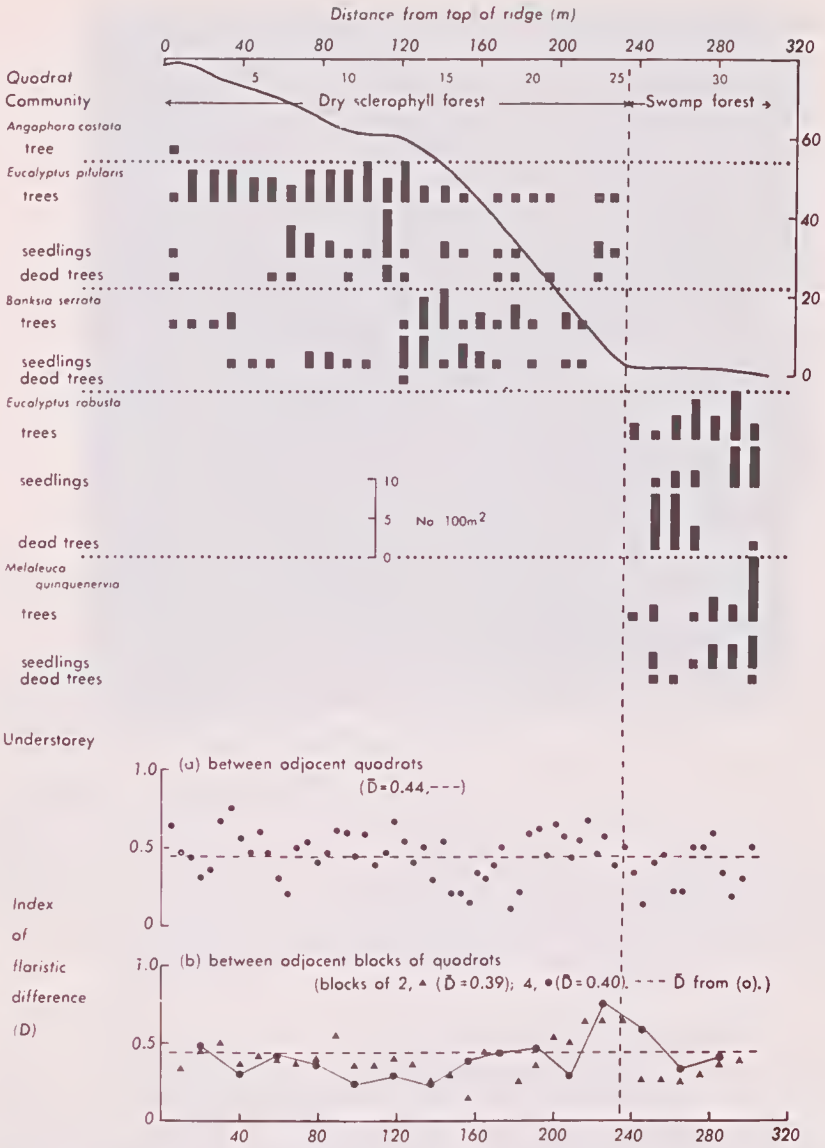


Figure 7. Transect (10 m wide) from ridge to lake down north-facing slope of dune adjacent to Myall Lake east of Kataway Bay (for approximate location see map located in back pocket), showing variation in surface topography, plant communities, and density of live and dead trees and tree seedlings (less than 2 m high). The plot of density, scored in 10 × 10 m quadrats laid on the ground surface, does not correspond with horizontal distance because of the slope. The designation of "Swamp Forest" near the top of the figure includes a narrow strip of Fringe Forest on the lake shore. Small trees of *Acacia implexa* (10 trees in quadrat 25) and of *Synoum glandulosum* (six trees in quadrat 25 and two in quadrat 26) and tall erect shrubs of *Pultenaea blakelyi* occurred at the ecotone between Dry Sclerophyll Forest and Swamp Forest. Variation in floristic composition of the understorey is shown in values of an index of floristic difference (D) between adjacent 5 × 5 m quadrats and between adjacent blocks of quadrats.

$$D = \frac{\sum\limits_{m=1\rightarrow n} \left| x_{mj} - x_{m(j+1)} \right|}{n}$$

multiple stems to 2-4 m high, occurs between Yagon Gibber and Big Gibber on seaward slopes that rise to the forest proper. *Eucalyptus pilularis* scrub also occurs locally on the small exposed hillocks and ridges above Wet Heath, immediately inland from the long, bare transgressive dune on Fiona and Submarine Beaches. The associated species seem to differ little from those in pure *E. pilularis* forest.

Fox (1979) has distinguished two types of shrubby understorey in Dry Sclerophyll Forest. One, in which fabaceous shrubs dominate, is associated with *Eucalyptus pilularis* and in the *E. pilularis* scrub mentioned above, while the other, a heathy understorey, occurs under *Angophora costata*-dominated canopy on higher ground. Fox & McKay (1981) indicate the relative extent of the two types of understorey in the area between Fiona and Submarine Beaches and Myall Lake, and also give data on the regrowth of *Aotus ericoides, Correa reflexa, Pteridium esculentum* and *Ricinocarpos pinifolius*, with *P. esculentum* achieving maximum cover within the first year following fire and declining in cover thereafter.

Under high fire frequency the usually shrubby understorey is apparently replaced by a more grassy understorey in which *Imperata cylindrica* is predominant. This tendency was also noted in southeastern Queensland and discussed by Coaldrake (1961). Dry Sclerophyll Forest with grassy understorey occurs near Seal Rocks where fires have been increasingly frequent over recent years.

The general composition of Dry Sclerophyll Forest is shown in two transects (Figures 7 and 8), both on scarp slopes. Although the two samples differ in composition, one with low frequency of *Angophora costata* (Figure 7) and the other with low frequency of *Eucalyptus pilularis* (Figure 8), variation down along each transect is small until relatively low on the slope, where presumably there is a relatively high water-table most of the time. Here a band of relatively shallow-rooted or water-demanding species occurs, for example, the rainforest species *Rhodomyrtus psidioides*, and Wet Sclerophyll species *Kennedia rubicunda, Pultenaea blakelyi* and *Acacia* spp. Also, *Gahnia clarkei*, a tussock sedge, frequently marks the boundary between Dry Sclerophyll Forest and swampy areas at the foot of sandy scarps.

The changing floristic composition of understorey plants across the boundary of the swampy areas and Dry Sclerophyll Forest is shown in Figures 7 and 8, in the variation of an index of floristic difference between adjacent blocks of quadrats. Values of the index for adjacent 5 x 5 m quadrats in the transects are on average higher than those for adjacent blocks of quadrats, and do not show such definite changes across the boundary between communities. Presumably values of the index at this scale reflect intrinsic patterns (Poore, 1964) within communities as much as differences across boundaries between them. In contrast, values of the index for adjacent blocks of quadrats reflect differences across the boundaries, showing maxima at the Dry Sclerophyll Forest/Swamp Forest boundary in each transect for each of the three block sizes examined.

Undoubtedly, the composition of the shrub stratum at any one site largely depends on its recent fire history, though no data are available to show this. In Figures 7 and 8 the Dry Sclerophyll Forest understorey was floristically very

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where x_{mj} is the occurrence of species m in quadrat j (with values of 1 if it is present; 0 if absent), and n is the total number of species in quadrats j and (j + 1) taken together.

The index is a simplified form of the Canberra metric, discussed earlier in the text. The simplification is two-fold: firstly, only binary data are used; and secondly, the value the index takes is local to each pair of quadrats or adjacent blocks of quadrats in a comparison. The value of the index varies between zero, when the species composition of the two quadrats is identical, and one when the quadrats have no species in common.

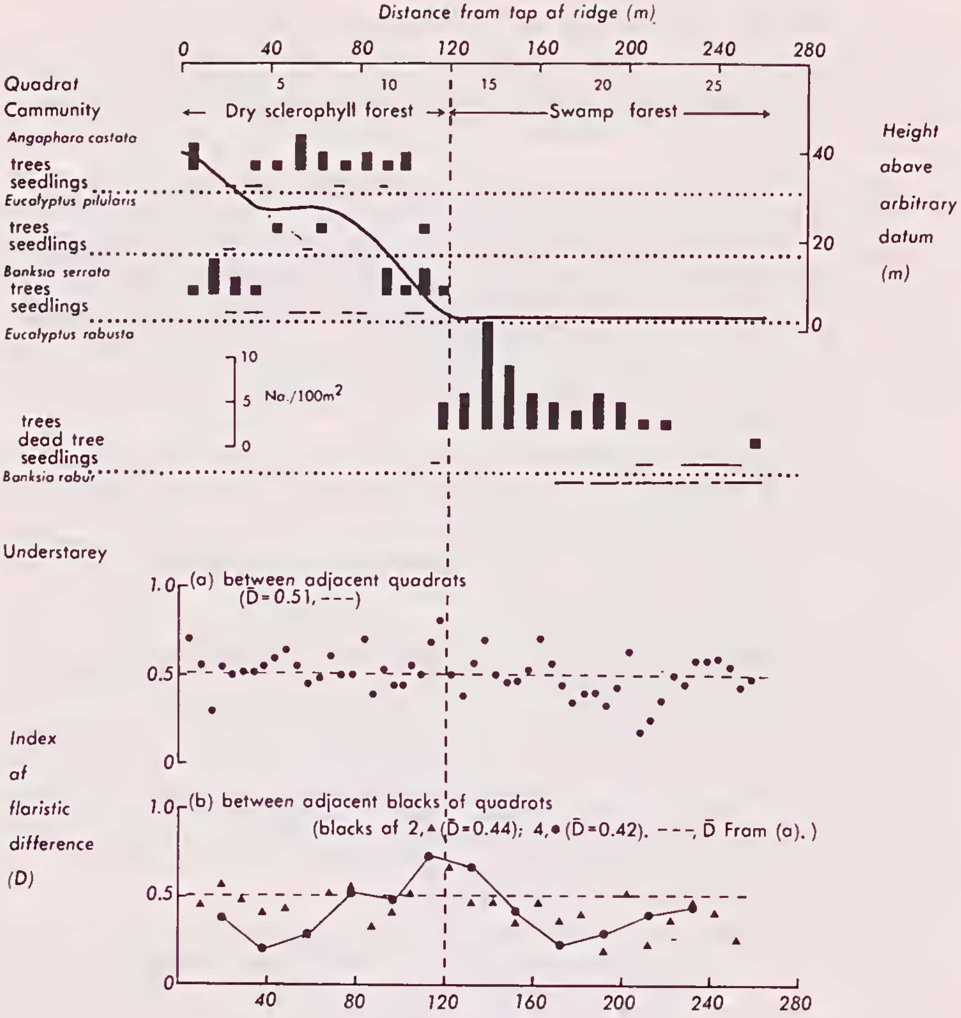

Figure 8. Transect from ridge top to swampy ground of the Eastern Lagoon down northwest facing slope of dune southeast of Kataway Bay (see map located in back pocket for approximate location of transect), showing variation in surface topography, plant community, density of living and dead trees, and the presence (—) of tree seedlings (<2 m high) and of *Banksia robur* shrubs. Tree density scored in successive 10 × 10 m quadrats; presence of tree seedlings and *B. robur* bushes in 5 × 5 m quadrats, together with understorey species. Variation in floristic composition of the understorey from the ridge top is shown in values of an index of floristic differences (see Figure 7) between adjacent quadrats and adjacent blocks of quadrats. The designation of Swamp Forest near the top of the figure also includes a strip (quadrats 22–27 inclusive) that could more correctly be termed Swamp.

similar in the two transects, with a value of 0.72 for Czechanowski's coefficient (see Greig-Smith, 1964).

There were in the first transect (Figure 7), omitting the ecotone (Quadrats 25 and 26), 32 understorey species in the Dry Sclerophyll Forest (forty-eight 5 x 5 m quadrats), with two species, *Aotus ericoides* and *Pteridium esculentum*, occurring in over 90 per cent of the quadrats and 11 species in under 10 per cent of them. In the Swamp Forest (twelve 5 x 5 m quadrats) there were 17 understorey species, with two, *Gleichenia dicarpa* R.Br. and *Baumea*

TABLE 4

Dry Sclerophyll Forest soils—chemical analyses of oven-dry samples

Transect No.	1 (Figure 7)								2 (Figure 8)			
Position of sample	ridge top			mid-slope			lower-slope		ridge top		mid-slope	
Depth (cm)	O–5	5–20	20–50	0–5	5–20	20–50	0–5	5–50	0–5	5–50	0–5	5–50
Loss on ignition (%)	7.3	2.5	0.5	3.3	4.3	0.1	6.5	2.1	8.2	0.1	9.5	0.6
Total nitrogen (%)	0.09	0.04	0.01	0.04	0.05	0.01	0.09	0.03	—	—	0.12	0.01
Total phosphorus (p.p.m)	35	32	20	25	—	—	24	22	51	18	30	7
Potassium (i) total (meq/100 g) . .	0.381	0.281	0.271	0.294	0.212	0.179	0.281	0.205	0.263	0.092	0.261	0.066
(ii) exchangeable	0.079	0.052	0.018	0.061	0.059	0.028	0.169	0.114	0.115	0.020	0.097	0.041
Exchangeable sodium (meq/100 g)	0.094	0.074	0.030	0.050	0.059	0.038	0.109	0.113	0.261	0.036	0.148	0.063
Exchangeable calcium (meq/100 g)	1.000	0.424	—	0.521	0.519	0.050	1.697	0.773	1.148	0.050	1.747	0.150
Total magnesium (meq/100 g) . .	1.275	0.066	0.271	1.192	0.123	0.181	0.905	0.197	0.146	0.024	0.658	0.484

— = not analysed. Analysis of total nitrogen by Kjeldahl method; of total phosphorus spectrophotometrically using ammonium molybdate on a neutralized nitric/perchloric/sulphuric acid digest; of K, Na, Ca and Mg with an atomic absorption spectrophotometer on an ammonium chloride extract for exchangeable cations, and on a neutralized nitric/perchloric/sulphuric acid digest for total amounts. (Methods used are mostly described in Allen *et al.* (1974), but the use of ammonium chloride to extract exchangeable cations is described in Piper (1950).)

arthrophylla, occurring in over 80 per cent and four species in under 10 per cent of the quadrats. Again omitting the ecotone, only two species, *Dianella caerulea* and *Kennedia rubicunda*, occurred in both communities.

There were in the second transect (Figure 8), also omitting the Dry Sclerophyll Forest/Swamp Forest ecotone (Quadrat 13), 38 understorey species in the Dry Sclerophyll Forest (twenty-four 5 x 5 m quadrats), with two species, *Dillwynia retorta* and *Pteridium esculentum*, occurring in over 90 per cent and nine species in under 10 per cent of the quadrats. In the Swamp Forest and Wet Heath taken together (twenty-eight 5 x 5 m quadrats), there were 40 understorey species, with three, *Blechnum cartilagineum* Sw., *Gleichenia dicarpa* and *Leptospermum juniperinum*, occurring in over 80 per cent and 12 species in under 10 per cent of the quadrats. Omitting the DSF/SF ecotone, only two species, *Pteridium esculentum* and *Leucopogon lanceolatus*, occurred in both communities and did so in the Swamp Forest only close to the ecotone.

Dry Sclerophyll Forest occurs most extensively on the high transgressive dunes of Holocene sand (map located in back pocket), but it is also characteristic of freely drained sites on old lake sand-bars (subsystem Lb in Figure 1) and on Inner Barrier sands round the base of old rock islands, such as McGraths Hill, often extending some distance from the bases of hills, particularly into the inner parabolic dunes. Dry Sclerophyll Forest soils generally show little profile development. Borings to 8 m deep on the high transgressive dune ridge east of Myall Lake, showed an incipient B horizon approximately 1 m deep. Casual observation elsewhere in the forest tends to confirm the general picture, as do observations of Anderson (1973) and Lewis (1973) in its northern areas and Lewis (1978) in Holocene dunes of the Outer Barrier southwest of Big Gibber.

The relatively low nutrient status of the soils (Table 4), also shown in more detailed observations by Lewis (1973, 1978), scarcely differs from that of Dry Heath Forest and Dry Heath soils on Pleistocene sands (Figures 11 and 20, pp. 427 and 438). As in Hawkesbury sandstone communities (Hannon, 1958), a higher proportion of nutrients in the ecosystem is probably in plant and animal tissues relative to soil components than in many other types of ecosystem.

INTERMEDIATE DRY FOREST (Figure 9)

Tree stratum (to c. 25 m): MAIAA *Eucalyptus pilularis*, AAADAA *Angophora costata*, CAFUF *Eucalyptus gummifera*.

Small tree stratum (to c. 8 m): *Banksia serrata*, *B. aemula*.

Shrub stratum (to c. 3 m): *Dillwynia retorta*, *Calytrix tetragona*, *Xanthorrhoea australis*, *Macrozamia communis*.

"Herb" stratum (to c. 1 m): *Pteridium esculentum*, *Coleocarya gracilis*.

Soils: podzols.

This forest, intermediate in structure and composition between Dry Sclerophyll Forest and Dry Heath Forest, is characteristic of the Late Pleistocene wind-blown sand sheet east of Bombah Broadwater, and of parts of the inner parabolic dunes whose surfaces may have been secondarily disturbed at some stage. Within it *Banksia serrata* and *B. aemula* occur together.

The trees of the main canopy are taller and better developed than in Dry Heath Forest but the canopy height never reaches the maximum attained in Dry Sclerophyll Forest.

DRY HEATH FOREST (Figure 10)

Tree stratum (to c. 20 m): MAIAA *Eucalyptus pilularis*, AAADAA *Angophora costata*, CAFUF *Eucalyptus gummifera*, *Melaleuca quinquenervia*.

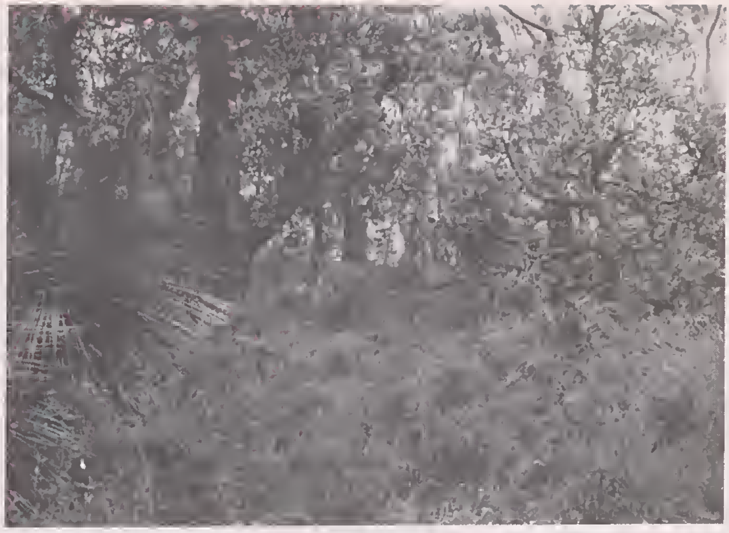

Figure 9. Intermediate Dry Forest on sands of the Glacial dune complex (Pg) east of Broadwater. *Banksia serrata*, *B. aemula*, *Eucalyptus gummifera*, *E. pilularis* with *Dillwynia retorta*.

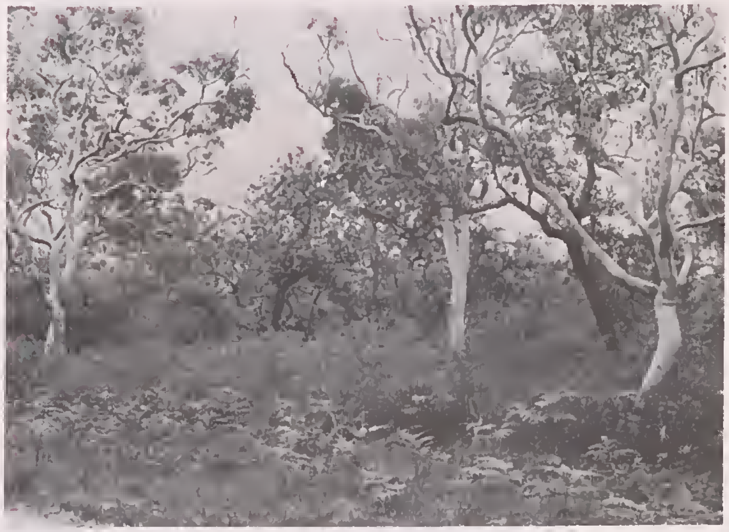

Figure 10. Dry Heath Forest on sands of differentiated Inner Barrier (Pib) between Bombah Broadwater and Johnsons Hill. *Angophora costata*, *Eucalyptus gummifera*, *Banksia aemula* with *Dillwynia retorta*, *Actinotus helianthi*.

Small tree stratum (to c. 3 m): *Banksia aemula*.

Shrub stratum (to c. 3 m): *Dillwynia retorta*, *D. glaberrima*, *Calytrix tetragona*, *Kunzea capitata*, *Leptospermum attenuatum*, *Melaleuca nodosa*.

"Herb" stratum: e.g., *Selaginella uliginosa* (Labill.) Spring, *Lomandra glauca*, *Hypolaena fastigata*, *Restio tetraphyllus* ssp. *meiostachyus*.

Soils: podzols.

Dry Heath Forest occurs on the Inner Barrier and is particularly well developed on the inner parabolic dunes. It has a number of species in common with Dry Sclerophyll Forest but there are notable differences. Particularly striking is the lack of *Banksia serrata*. On the other hand *B. aemula* is common in Dry Heath Forest but absent from Dry Sclerophyll Forest. *Eucalyptus gummifera* is common in Dry Heath Forest but absent from Dry Sclerophyll Forest except in the northeastern parts of this area and a narrow strip between Big Gibber and Yagon Gibber, which may be caused by rocky bars below the sand or an old Pleistocene surface that is only just covered.

The overall tree density is considerably less than in Dry Sclerophyll Forest. Indeed, locally, tree canopies are so widely spaced that the community is structurally a woodland. The whole aspect is one of lower productivity than in the Dry Sclerophyll Forest although there are no quantitative data on this point. The soils certainly show a very distinct difference, displaying a well developed podzol profile, with B horizon being located at 1.5 m or deeper.

To some extent the presence of Dry Heath Forest may be determined by the average height of the water-table, particularly on the differentiated Inner Barrier. Thus the higher ridges carry Dry Heath Forest, the trees getting more and more depauperate as the ridges decrease in height and giving way to Dry Heath on the lower slopes and the lower ridges. On the inner parabolic dunes, however, Dry Heath Forest tends to be replaced by Wet Heath as the altitude decreases with scarcely any intervening Dry Heath (Figure 11). The difference may be due to fire frequency as indicated under Dry Heath. On the peninsula south of Pigeon Point, where greater protection from fire might be expected, Dry Heath Forest on the gentle slopes into the central depression gives way down-slope to a community with an open Swamp Forest canopy and a Wet Heath understorey (Figure 12). Similar transitions also occur near McGraths Hill and Kataway Hill where a similar degree of protection from fire might also be expected.

WET HEATH FOREST (Figure 13)

Tree stratum (to c. 20 m): AAADAA *Angophora costata*, SECAF *Eucalyptus robusta*, *Melaleuca quinquenervia*.

Small tree stratum (to c. 5 m): *Melaleuca sieberi*.

Shrub stratum (to 2 m): *Banksia oblongifolia* R.Br., *Melaleuca nodosa*, *Acacia elongata*, *Xanthorrhoea resinosa* ssp. *fulva*.

"Herb" stratum: *Schoenus brevifolius*, *Baumea rubiginosa*, *Empodisma minus*, *Panicum simile*, *Gonocarpus micrantha*, *Restio tetraphyllus* ssp. *meiostachyus*.

Soils: humus podzols.

Wet Heath Forest has a well developed tree canopy. The ground surface is usually uneven and poorly drained with small shallow pools remaining in lower spots for some time after rain. The composition of the understorey accordingly varies with the microtopography and ranges from species occurring in Swamp Forest to those occurring in Wet Heath and on lower sites in Dry Heath Forest.

Wet Heath Forest characteristically occurs on low-lying ridges and gentle slopes on Pleistocene sands of the early Inner Barrier (Pu), undifferentiated Inner Barrier (Pub) and inner parabolic dunes (Pip). It is the most extensive type of forest on the low ridges on the northern and western sides of Eastern Lagoon near McGraths Hill and Kataway Hill.

Small trees of *Melaleuca sieberi* up to 5 m high occur in the wettest facies of Wet Heath Forest with *Baumea arthrophylla*, B. *rubiginosa* and *Schoenus brevifolius*. *Melaleuca sieberi* occurs as a shrub to 2 m high in Wet Heath on the differentiated Inner Barrier (Pib) where more frequent and intense burning

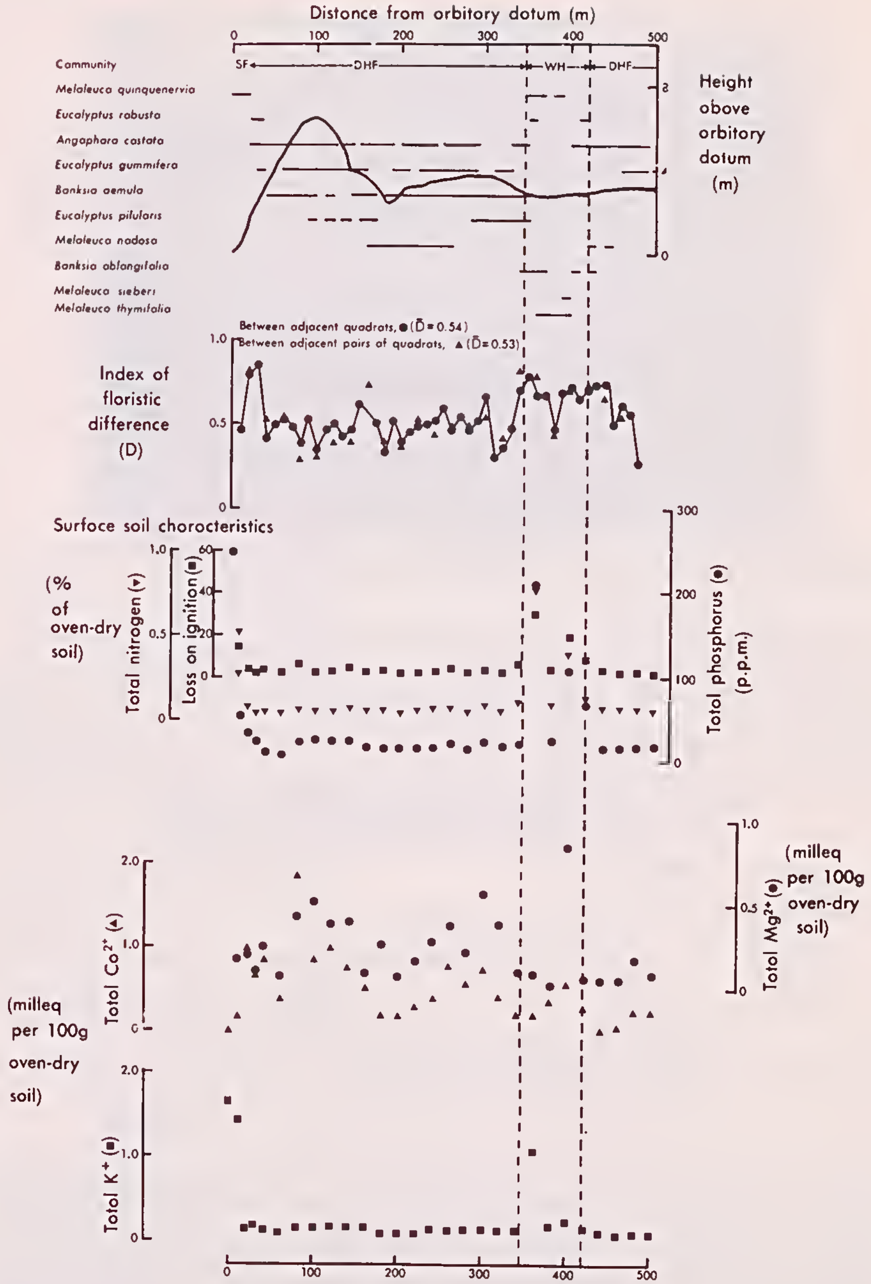

Figure 11. Transect approximately west to east across the junction of the inner parabolic dunes and differentiated Inner Barrier between Tickerabit and Johnsons Hill (see map located in back pocket for approximate location), showing variation in surface topography, plant community, and the presence (—) of tree species scored in 10 × 10 m quadrats and species of shrubs of the same genera as the trees present but scored in quadrats 10 m long and 5 m wide. Variation in floristic composition of the understorey in the forests and the main canopy in Wet Heath is shown in values of the index of floristic differences between adjacent 5 × 5 m quadrats and adjacent pairs of quadrats (see Figure 7). Variation of characteristics of the top 5 cm of soil below the litter layer is shown. (For methods of soil analysis see Table 4. For abbreviations of plant communities see Table 2).

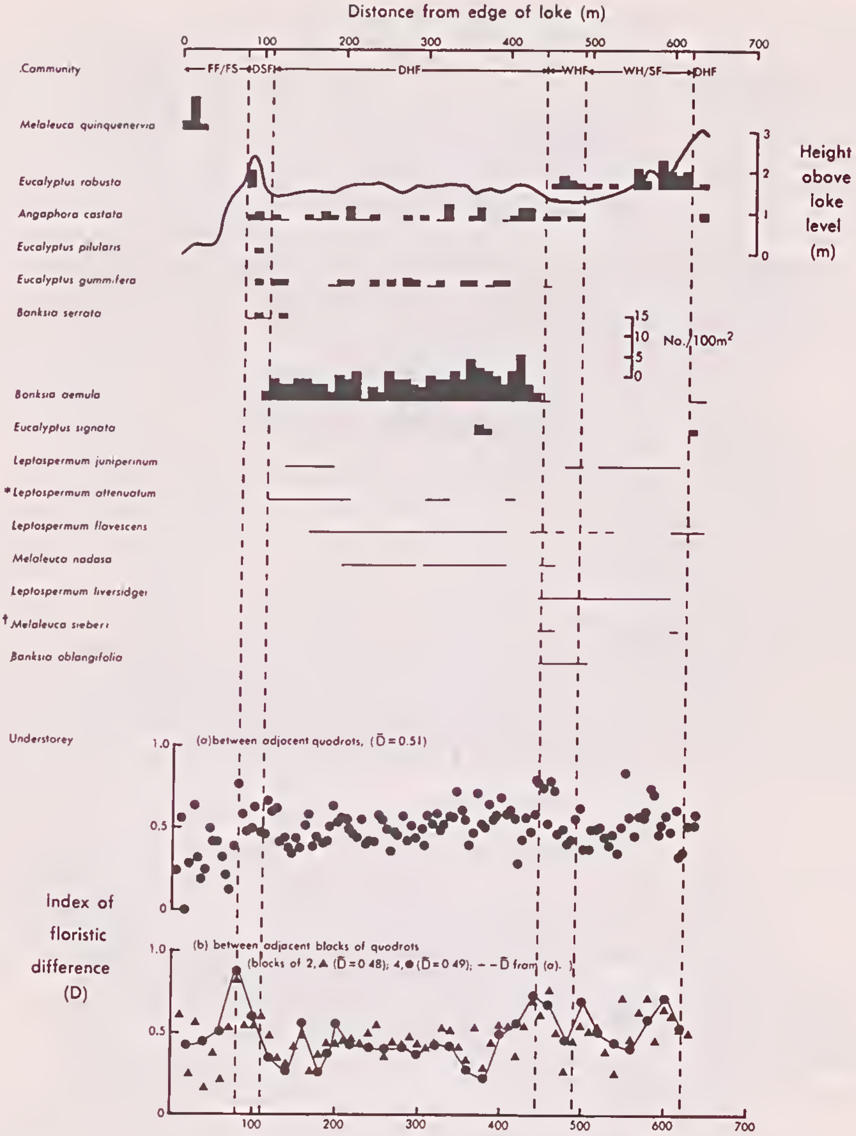

Figure 12. Transect approximately southwest to northeast from the lake edge on the western side of the peninsula south of Pigeon Point (for approximate location of transect see map located in back pocket), showing variation in surface topography, plant community density of live trees in successive 10 × 10 m quadrats. The presence (—) in successive quadrats 10 m long and 5 m wide of seedlings and saplings of each of the main species of trees is shown where live trees were not already recorded for it in a given 10 × 10 m quadrat. The presence (—) of shrubs is similarly shown where they belong to species in the same genera as the tree species. However presence (—) was recorded in *Leptospermum attenuatum** from data compounded from scoring small trees in 10 × 10 m quadrats and understorey individuals in 10 × 5 m quadrats and in *Melaleuca sieberi*† from individual small trees in 10 × 10 m quadrats. Variation in floristic composition of the understorey scored in successive 5 × 5 m quadrats is shown in values of an index of floristic differences (see Figure 7) between adjacent quadrats and adjacent blocks of quadrats. Communities designated near the top of the figure as WHF and WH/SF were ecotonal and were mapped on the map located in back pocket as DHF and WH respectively. (For abbreviations of names of communities see Table 2).

* scored as trees and shrubs

† scored as trees

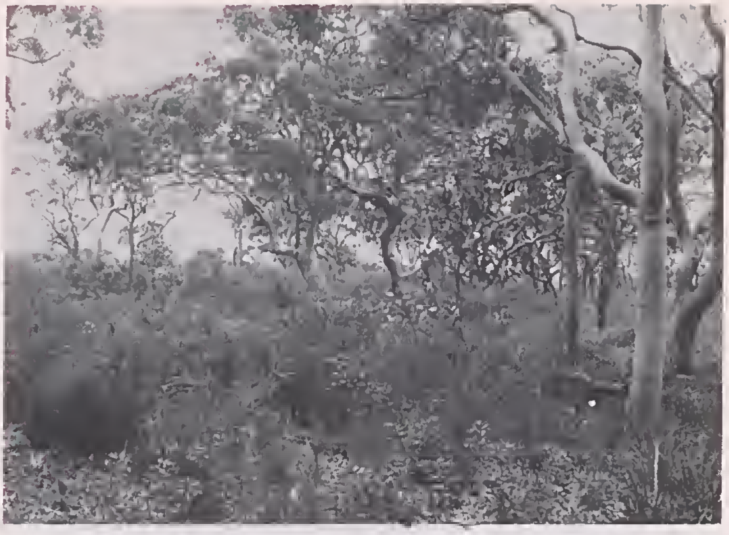

Figure 13. Wet Heath Forest on sands of differentiated Inner Barrier (Pib) at the southeastern edge of Johnsons Hill. *Angophora costata* with *Banksia oblongifolia, Leptocarpus tenax, Restio tetraphyllus.*

may occur (see comment under Dry Heath). It may be partly fire regime that limits Wet Heath Forest to sheltered areas on Pleistocene sand, in contrast to exposed situations where it is replaced by Wet Heath. Where Wet Heath Forest occurs close to the rock-based prior islands, species such as *Banksia spinulosa* and *Pultenaea microphylla* are present. This presence may be due to some downwash enrichment. In other places Wet Heath Forest appears to be an extended ecotone between Dry Heath Forest and Swamp Forest.

SWAMP FOREST (Figure 14)

Tree stratum (to 20 m): *Melaleuca quinquenervia,* SECAF *Eucalyptus robusta.*

Small tree stratum: almost always absent.

Shrub stratum (to 2 m): *Leptospermum juniperinum, Acacia elongata;* often absent.

"Herb" stratum: *Blechnum cartilagineum* Sw., *B. campfieldii* Tindale, *Restio tetraphyllus* ssp. *meiostachyus, Chorizandra sphaerocephala, Baumea athrophylla.*

Soils: almost no profile development, very high organic matter from surface downwards.

Swamp Forest, equivalent to Tree Swamp of Anderson (1973), is dominated in the tree layer by *Melaleuca quinquenervia* and *Eucalyptus robusta.* The proportions of these species vary, but their presence or absence does not seem to be related to the relative depth of water. However, while *E. robusta* is usually the more abundant in sites with appreciable waterflow, *M. quinquenervia* is usually the more abundant in "sump" sites where water stands or seeps into the ground when the water-table drops. *Melaleuca quinquenervia* tends to show stepping of size classes. This feature is often in the sapling stages and implies that regeneration occurs only under certain periodically realized conditions. In Swamp Forest the relative water-table is high and accumulation of soil organic matter is presumably related to this factor. Figure 11 shows that loss on ignition is high in these soils and that the nutrient status is also high, particularly in total nitrogen and phosphorus.

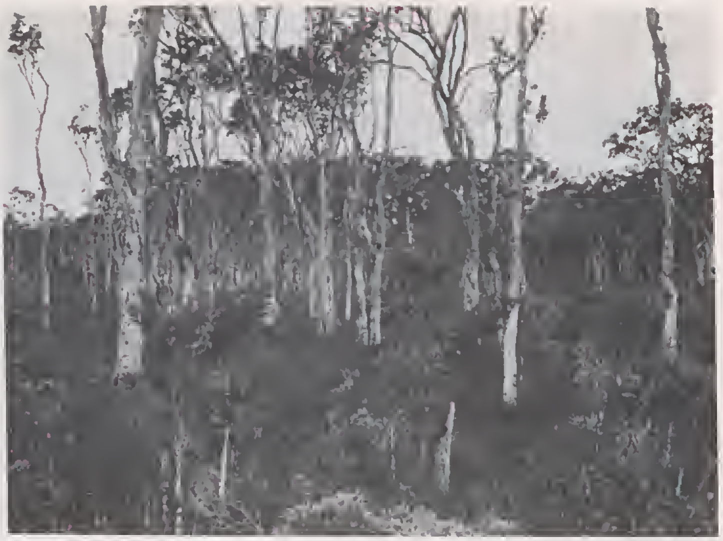

Figure 14. Swamp Forest at the eastern end of the inter-Barrier lagoon (Pil). *Melaleuca quinquenervia* with *M. sieberi, Callistemon citrinus, Restio* spp.

In typical Swamp Forest there is much colloidal organic material in the soil and the ground flora consists largely of *Blechnum camfieldii, Villarsia exaltata, Chorizandra sphaerocephala* and *Baumea arthrophylla.* With continued accumulation of organic matter, the soil surface is raised and species requiring somewhat drier conditions appear, such as *Blechnum cartilagineum, Gahnia sieberiana, Spartothamnella juncea, Callistemon citrinus,* and *Empodisma minus. Empodisma minus,* in particular, marks a significant change in the character of Swamp Forest. It tends to build up large hummocks and to form peaty islands which are colonized by Wet Heath species, particularly the smaller growing ones such as *Epacris obtusifolia, Sprengelia* spp. and *Schoenus brevifolius.* Indeed, the situation on these islands can be almost ecotonal (see Figure 20, p. 438) and in general may represent a phase in the supplanting of Swamp Forest by Wet Heath. Swamp Forest trees, particularly *Melaleuca quinquenervia,* survive in increasingly heathy conditions better than the ground flora of this community and are possibly eliminated eventually by increased fire frequency or intensity.

Swamp Forest is scattered throughout the Eurunderee sand mass wherever the water-table is at or very near the surface. There are, however, exceptions to this generalization that are discussed under Swamp and *Lepironia* Swamp. Swamp Forest is particularly common amongst the inner parabolic dunes. There are also narrow strips in the lower parts of the differentiated Inner Barrier and along the base of the landward scarp of the Outer Barrier. Such a strip of Swamp Forest widens into a very extensive area towards the outlet of the inter-Barrier lagoon into Broadwater.

There are patches of Swamp Forest in the Outer Barrier, including two in the large, high sand mass in the northeast of the area. It is possible that such patches are growing on parts of the older land surface over which sand of the Outer Barrier was blown.

Osborn & Robertson (1939) drew attention to a particular facies of Swamp Forest, containing *Livistona australis,* near Mungo Brush, which is beyond the limits of this survey. *Livistona australis* occurs in a wind-pruned thicket of *Melaleuca quinquenervia* behind a semi-mobile foredune 500 m northwest of Treachery Head. This thicket has been mapped as Swamp Forest in the map located in the back pocket, though its understorey is more characteristic of

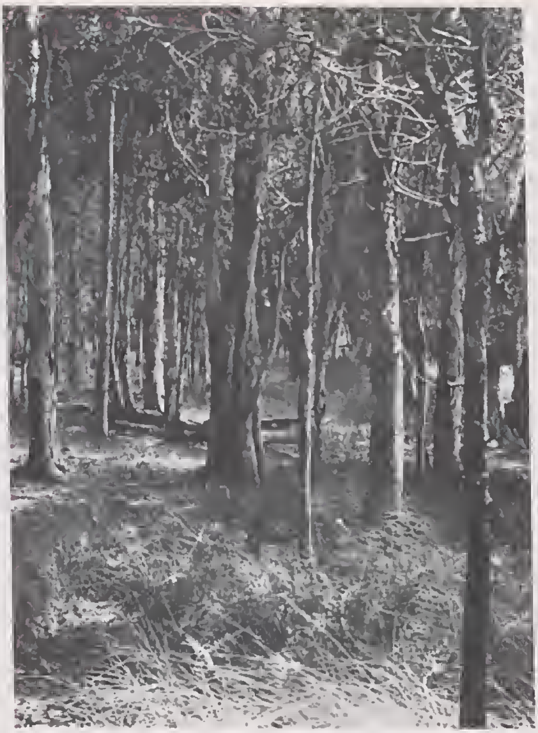

Figure 15. Fringe Forest on shores of Bombah Broadwater near Nerong (Dirty) Creek (out of the study area to the northwest). *Melaleuca quinquenervia, Casuarina glauca* with *Baumea* spp.

Beach-dune Thicket, its soil surface having been raised by recently arrived wind-blown sand.

FRINGE FOREST (Figure 15)

Tree stratum (to 20 m): *Casuarina glauca, Melaleuca quinquenervia.*

Shrub stratum: usually lacking.

"Herb" stratum: *Baumea juncea, B. articulata, Cladium procerum.*

Soils: various, but usually highly organic and highly reducing with no profile development.

This forest, the Lake Margin Association of Anderson (1973), occurs in a thin strip along the margins of the lakes and, for the purpose of this description, includes their emergent communities.

The two main tree species frequently grow together but, generally, at the bases of the old rocky islands *Casuarina glauca* tends to dominate whilst on the sands themselves *Melaleuca quinquenervia* is the more abundant. *Dendrobium teretifolium* and *Platycerium bifurcatum* (Cav.) C. Chr. occur as epiphytes of *Casuarina glauca.* The herb stratum is often dominated by *Baumea juncea,* particularly away from the immediate lake edge. At the lake edge and extending into standing water *Baumea articulata* and *Cladium procerum* tend to form extensive communites excluding other species. Rafts of *Cladium procerum* grow out over the water and break off, at least at their extremities, when heavy winds occur in the right direction, so there is no general extension of the sedgebeds. In standing water over mud, *Schoenoplectus validus* often

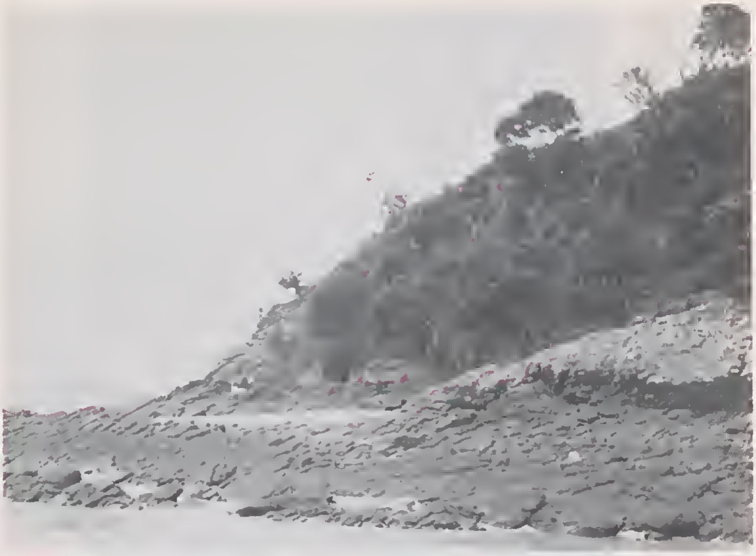

Figure 16. Headland Thicket at southern end of Number One Beach, Seal Rocks. *Banksia integrifolia* with *Melaleuca armillaris.*

occurs, thinly spread, sending out rather superficial rhizomes into deeper water. Once again, with strong onshore or alongshore winds these rhizomes are torn up and there is no general extension. Stands of *Phragmites australis* are frequent in standing water over a sandy or rocky substratum. The extension of this species into the lakes seems to be controlled by factors other than direct wind or wave action since it produces rhizomes deeper in the substratum than *Schoenoplectus validus.*

Along the shores of Smiths Lake, the lakeward edge of the Fringe Forest is higher above the average lake level than it is in the Myall Lakes system. This distribution pattern can be related to the greater salinities, similar to or even slightly above those of the sea, that the waters of Smiths Lake attain. *Juncus krausii* is commoner at its lakeward edge than it is in the Myall Lakes system. Also, *Cladium procerum* and *Schoenoplectus validus* do not extend outwards from its shores, and *Sarcocornia quinqueflora*, absent from the shores of the other lakes, occurs on saline muddy flats in sheltered bays.

HEADLAND THICKET (Figure 16)

Small tree stratum (to c. 8 m): e.g., *Cupaniopsis anacardioides, Banksia integrifolia, Synoum glandulosum, Acmena smithii.*

Shrub stratum (to c. 3 m): Same species as trees, together with *Breynia oblongifolia, Acacia longifolia.*

"Herb" stratum: e.g., *Hibbertia scandens, Oplismenus imbecillis, Imperata cylindrica, Themeda australis.*

Soils: black headland soils.

A thicket consisting of a mixture of rainforest and sand-dune species is found facing the sea on the rocky headlands of Big Gibber, Yagon Gibber, Treachery Head and some of the cliffs near Seal Rocks. The trees are usually severely affected by the onshore winds, particularly towards the seaward side where the relatively salt-wind tolerant *Cupaniopsis anacardioides* and *Banskia integrifolia* occur as stunted wind-pruned bushes. Near Seal Rocks, *Melaleuca*

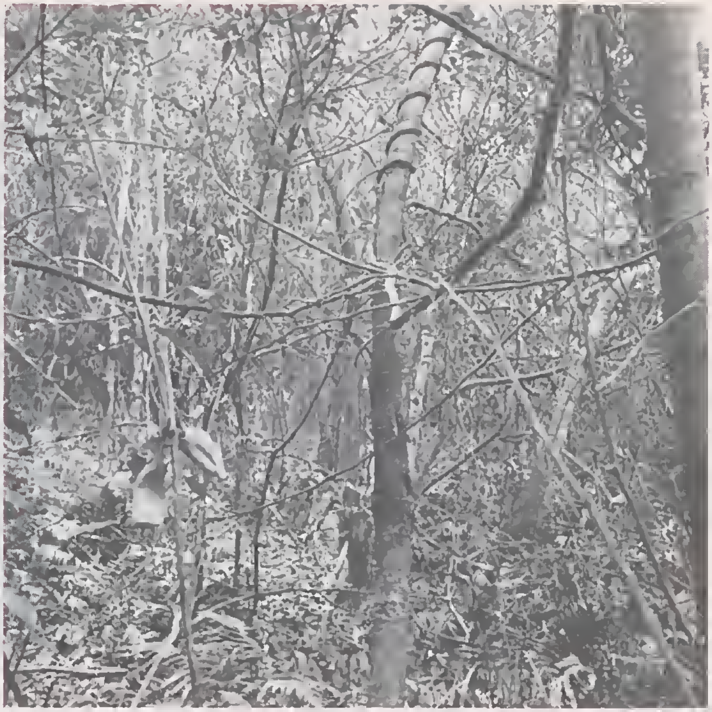

Figure 17. Vine Thicket west of Number One Beach, Seal Rocks. Stems mostly of *Eupomatia laurina* with mainly *Cissus hypoglauca* and *Blechnum cartilagineum, Doodia aspera.*

armillaris occurs in this situation. Within the shelter of these trees to landward, the less tolerant species, such as *Synoum glandulosum, Acmena smithii* and *Trema aspera* occur, often with extensive lianas or semi-lianas, for example, *Hibbertia scandens, Cissus antarctica, Stephania japonica* and *Kennedia rubicunda.* The individual headlands show relatively minor differences, presumably due to different histories or rock-types. For instance, Yagon Gibber has many more introduced species such as *Chloris gayana, Paspalum dilatatum* and *Pennisetum clandestinum,* than Big Gibber. Moreover, on Yagon Gibber a large area of grassland extends seaward beyond the thicket, and contains many of the introduced species together with *Themeda australis* and *Lomandra longifolia,* scattered shrubs of *Westringia fruticosa* and many Foredune Complex species, for example, *Correa alba, Isolepis nodosa, Carpobrotus glaucescens* and *Hydrocotyle bonariensis.* The steeper cliffs north of Seal Rocks are often very wet from springs in the joints and carry many Foredune Complex species.

Headland Thicket includes the Headlands and Rocky Outcrops Association (fd. 2) of Anderson (1973) and the more coastal facies of her Depauperate Relic Vine Shrub Community.

VINE THICKET (Figure 17)

Small tree stratum (to c. 8 m): e.g., *Rhodomyrtus psidioides, Acmena smithii, Eupomatia laurina, Cupaniopsis anacardioides, Banksia integrifolia.*

Lianas: *Smilax australis, Cissus hypoglauca.*

Soils: yellow podzolic.

This dense thicket occurs in a broad shallow gully sloping fairly steeply and facing the sea. The Seal Rocks road descends to the shore along its southern

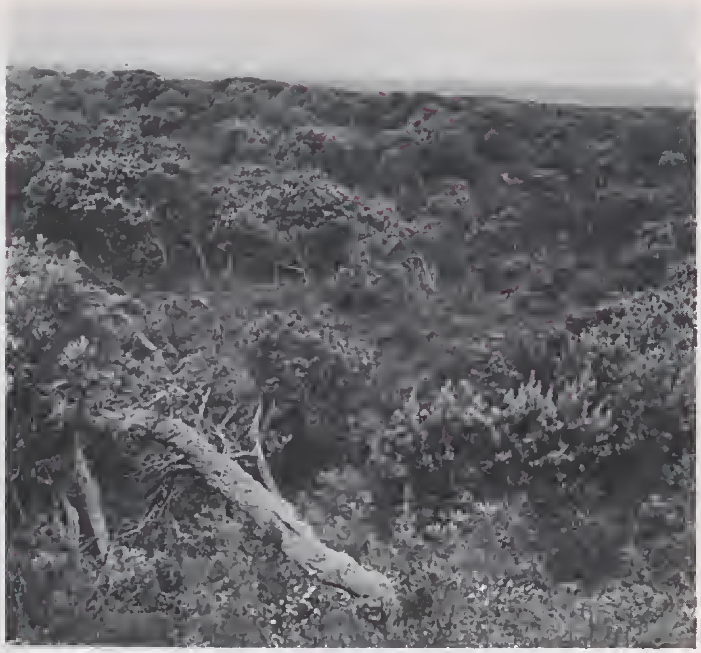

Figure 18. Beach-dune Thicket south of Bombah Broadwater. *Banksia serrata* in foreground with *Leptospermum laevigatum* on more seaward ridge in the middle distance.

side. The gully appears to be more sheltered from onshore winds and to receive a better supply of groundwater than otherwise similar rock-based gullies to the north. The close cover of low trees, mostly of rainforest species with a dense tangle of vines, makes this community difficult to traverse. There is little or no groundcover but shade-tolerant ferns such as *Doodia aspera* R. Br. occur locally. To seaward and along its northern edge the community grades into Headland Thicket, with which it has species in common such as *Banksia integrifolia* and *Cupaniopsis anacardioides*. At the head of the gully it grades into Wet Sclerophyll Forest, which in turn grades into a facies of Dry Sclerophyll Forest rich in *Dodonaea triquetra*, with a quantity of *Acacia parramattensis* across the ecotone. The Vine Thicket community is probably a stage in regrowth following the destruction of a taller forest canopy. Certainly at the head of the gully there are several tall dead standing eucalypt stems.

Anderson (1973) includes this community within her more broadly defined Depauperate Relic Vine Community.

BEACH-DUNE THICKET (Figure 18)

Small trees (to c. 8 m): *Banksia serrata, Banksia integrifolia, Leptospermum laevigatum, Cupaniopsis anacardioides, Pittosporum undulatum.*

Shrub stratum (to c. 3 m): *Dodonaea triquetra, Acacia longifolia, Correa reflexa.*

"Herb" stratum: *Pteridium esculentum, Gonocarpus teucrioides, Tetratheca thymifolia, Imperata cylindrica, Cymbopogon refractus.*

Soils: sand with minimal profile development, an organically stained A_1 horizon grading into undifferentiated beach-sand.

This community occurs at certain sites along the sea front but is generally protected by the foredune. In many places the foredune is broken through in long parabolic blow-outs or more complicated areas of disruption and in such

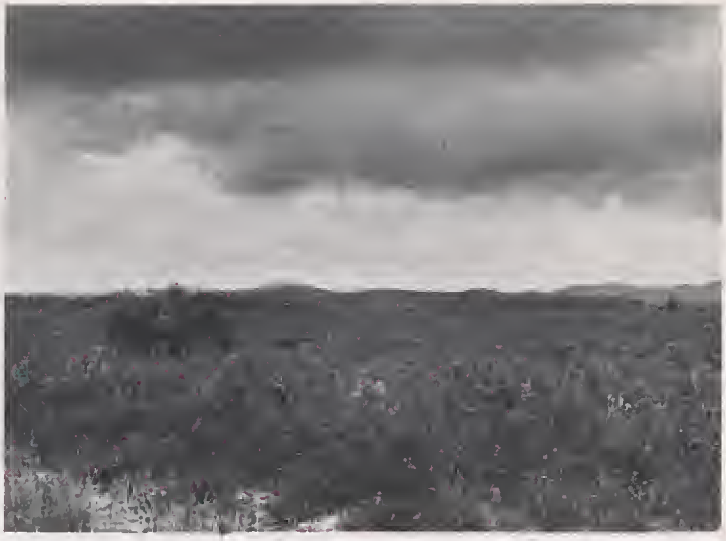

Figure 19. Dry Heath on ridge of differentiated Inner Barrier (Pib) about 1.5 km northwest of Big Gibber. *Banksia aemula, Acacia suaveolens.*

cases the Beach-dune Thicket may be exposed to the sea. In these recent blowouts, except right at their mouths, it is the species of this community that colonize the bare sand and generally not those of the Foredune Complex. It seems that the early stages of Pidgeon's (1940) sand-dune succession can only be applied to a prograding beach. Otherwise the situation is, strictly speaking, a zonation, which may show little if any change over appreciable periods of time, and can be related in part to the relative degree of protection from onshore winds. It is on the landward lee slopes behind the beach-dune that the rather more mesic species occur such as *Cupaniopsis anacardioides, Synoum glandulosum, Pittosporum undulatum* and even the distinctly rainforest species *Acmena smithii.*

The community includes the Hind Dune Scrub Community of Anderson (1973) and probably the more shrubby facies of her Sandy Foredunes Associations (fd. 2).

DRY HEATH (Figure 19)

Shrub stratum (to 2 m): mainly the same shrubs as found in Dry Heath Forest together with stunted specimens of CAFUF *Eucalyptus gummifera,* and very occasionally MAIAA *E. pilularis* and AAADAA *Angophora costata.*

"Herb" stratum: mainly the same as in Dry Heath Forest.

Soils: podzols with B horizon 1-1.5 m below the surface.

On the differentiated Inner Barrier, Dry Heath occurs on flanks of the higher dunes between Dry Heath Forest and Wet Heath, and on summits of the lower dunes as shown in Figure 20. It occupies an intermediate position with regard to water-table between these two communities. However, as was indicated when discussing Dry Heath Forest, Dry Heath, which is virtually Dry Heath Forest without trees, is not found in intermediate situations on the inner parabolic dunes. The low relief and parallel form of the ridges of the differentiated Inner Barrier may enable fires to sweep over them more frequently and with greater intensity than the more complex parabolics with somewhat higher relief. Local tradition is that fires have been more frequent on the "moors" as the differentiated Inner Barrier is known locally. Such a severe fire regime may prevent growth of Dry Heath Forest trees when the water-table is relatively high.

Root excavation in Dry Heath Forest close to Wet Heath boundaries has shown that roots of *Angophora costata* and *Eucalyptus pilularis* penetrate below the B horizon but, since all these roots were found to be dead after a periodic but irregular rise of the water-table to the B horizon, it seems that lower portions of the root-system must be renewed after each such rise of water level. Thus, effective exploitation of the soil by the root systems of these species is relative to average depth of water-table. The apparently more severe fire regime on the differentiated Inner Barrier may periodically greatly damage shoot systems with resultant reduced capacity for renewal. On the inner parabolic dunes, shoot damage may be generally less severe and less frequent. It seems probable that Dry Heath is in Clements' (1936) terminology, a disclimax, resulting from an interaction of fire-exposure and water-table fluctuation.

Eucalyptus pilularis has no lignotuber and does not survive as a small tree through a very high fire frequency or intensity. However, *Eucalyptus gummifera*, a lignotuberous species, can apparently stand up rather more effectively to burning and high water-table. This species occurs in Dry Heath with an almost mallee growth-form, often with numerous stems arising from large lignotubers at ground level, as described in the occurrence of the species on certain Hawkesbury sandstone areas in the Sydney region (Mullette, 1978). MAG:C *Eucalyptus acmenoides* also occurs in a low mallee form locally in Dry Heath on the differentiated Inner Barrier, occasionally reaching about 8 m in patches of Dry Heath Forest (M. Fox, pers. comm.).

Banksia aemula is very common, but is also reduced to a shrub with a large lignotuber-like mass. Outward growth from this mass following periodic burning results in divisions of the original plants into separate units. Patterns of distribution of this species in Dry Heath indicate repeated division of the original plants (Siddiqi, 1971). Other species that survive fires in lignotuber-like masses, such as *Melaleuca nodosa*, may also show a similar pattern. Yet other species, such as *Dillwynia* spp., *Epacris*, spp. and *Boronia* spp., regenerate after fire from seed. Thus the relative abundance of species in any one area may depend on its fire history, although Siddiqi, Carolin & Myerscough (1976) have shown that recovery in terms of species presence can be remarkably quick in coastal heath.

Whilst Dry Heath occurs mainly on the differentiated Inner Barrier one very interesting outlier (though mostly destroyed by sand mining) occurs in a very different topographical situation, on the perched dune of Pleistocene sand on the northern side of Big Gibber. It differs from the main area of Dry Heath in having a greater abundance of stunted *Eucalyptus gummifera*, but its species composition seems to be similar.

WET HEATH (Figure 21)

Shrub stratum (to c. 2 m): *Banksia oblongifolia, Xanthorrhoea resinosa* ssp. *fulva, Hakea teretifolia, Dillwynia floribunda, Leptospermum liversidgei, L. juniperinum.*

Undershrub stratum (to 1 m): *Bauera rubioides, Boronia parviflora, Epacris microphylla, E. paludosa, E. obtusifolia.*

"Herb" stratum: *Blandfordia grandiflora, Burchardia umbellata, Lepyrodia interrupta, Restio complanatus.*

Soils: Humus podzols.

The distinction between Wet Heath and Dry Heath is only slightly clearer than between Dry Heath Forest and Dry Heath. All three communities represent slightly different, but distinguishable, reactions to different conditions on the dunes of the Inner Barrier. Wet Heath occurs where the water-table is high enough for the formation of humus podzols but is not high enough to interfere with profile development as in Swamp Forest.

The Inner Barrier dune slopes show a most interesting distribution of species. Carolin (1971) has shown that within several genera, the species replace each other vicariously down the slope. Giving the Dry Heath species first and progressing down the slope, notable sequences are: *Dillwynia retorta–D. glaberrima–D. floribunda; Boronia pinnata–B. falcifolia–B. parviflora* and *Leptospermum attenuatum–L. flavescens–L. juniperinum–L. liversidgei.*

Each species has a limited range, but the position down the gradient at which one species replaces another differs between genera, so that on a gently sloping surface the change in species composition of the vegetation is gradual and continuous, and does not show in clear-cut changes in the values of the index of floristic difference between alternate 5 × 5 m quadrats or successive pairs of alternate quadrats (Figure 20). Although boundaries between Wet Heath and Dry Heath are difficult to set up at any one site, the data from the long transect indicated that Wet Heath can be distinguished on the associated occurrence of species (Figure 2). Williams (1968), using an hierarchial arrangement based on polythetic classification, found that groups corresponding to Dry Heath, Wet Heath and Swamp Forest defined in Figure 2 could be recognized.

Many Wet Heath species show similar features of survival through fire to those already discussed in Dry Heath species and reported in previous accounts of heath vegetation in Australia.

Interesting outliers of this community occur behind the long bare transgressive dune on Fiona and Submarine Beaches, between Yagon Gibber and Big Gibber. Wet Heath covers the flanks and, in some cases, the summits of slight rises between Swamp Forest remnants. This complex has mostly been destroyed by recent sand mining.

The Scrub Swamp Association of Anderson (1973), with *Banksia robur* and *Leptospermum liversidgei*, is a form of Wet Heath characteristic of sites with marked seasonal groundwater movement, and peat accumulation between fires. It is scattered through the inner parabolic dunes but it is most extensive and best developed on the Pleistocene sand surfaces near the foot of the high Holocene transgressive dunes (e.g., Figure 8), especially behind the embayment on Myall Lake southeast of Neranie, and in the area south of Horse Point. Here the water-table of the high dunes may be expected to rise and emerge seasonally.

SAND GRASSLANDS (Figure 22)

Trees and shrubs: absent or tree and shrub species present only as scattered low-growing individuals (< 0.5 m high).

"Herb" stratum: *Themeda australis, Imperata cylindrica, Lomandra longifolia, Isolepis nodosus, Cymbopogon refractus, Pteridium esculentum, Senecio spathulatus, Stephania japonica, Eragrostis brownii.*

Soils: weakly developed podzols with organically stained A_1 horizon and shallow B horizon apparent but no A_2 horizon.

Sand Grassland is limited to steep sand slopes facing the ocean north to northeast along the stretch of coast between Number One Beach and the entrance to Smiths Lake. Scattered within it there are low plants of taller growing woody species such as *Banksia integrifolia, Notelaea ovata* and *Monotoca elliptica.* Sand Grassland may be an ephemeral community depending for its continued existence on a high incidence of fire under exposure to onshore

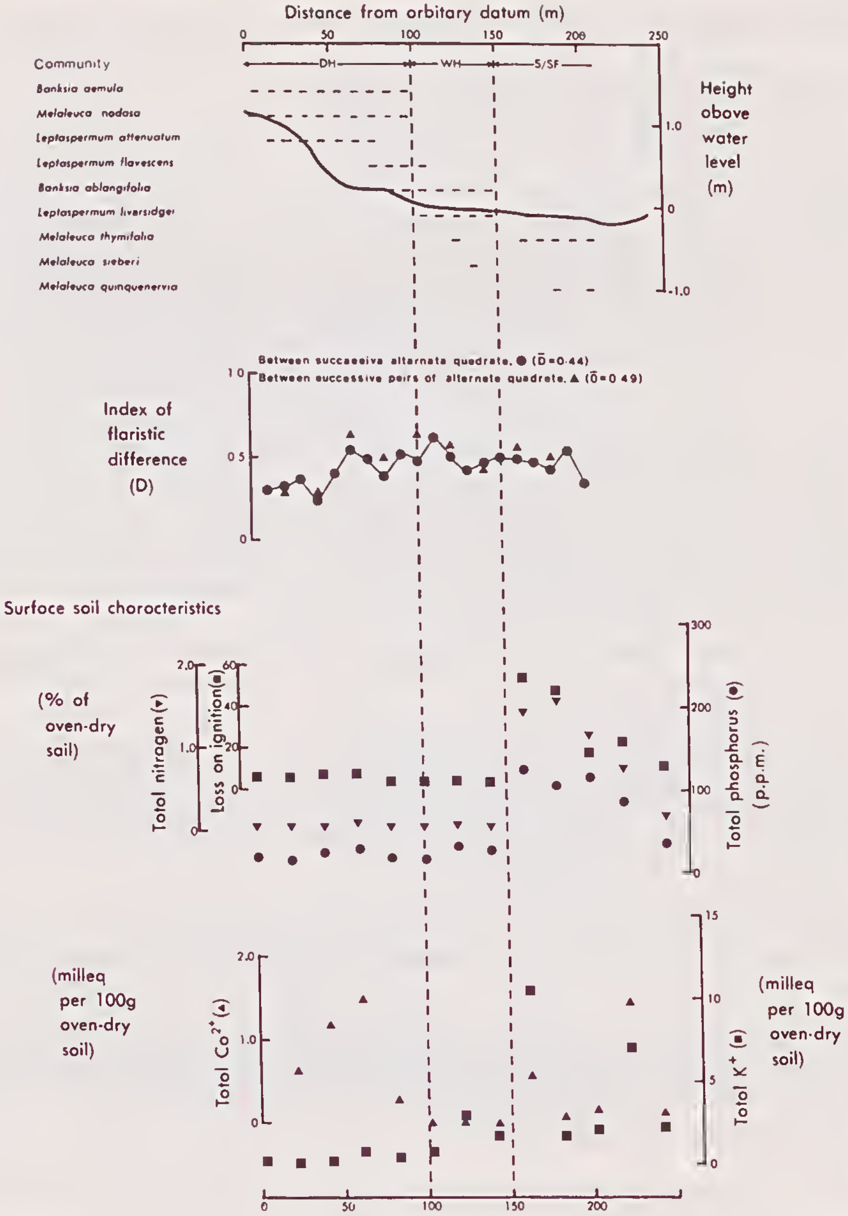

Figure 20. Transect approximately south to north from near to the top of one of the most inland dune-ridges of the differentiated Inner Barrier south of McGraths Hill (see map located in back pocket for approximate location of transect), showing variation in surface topography, plant community, and the presence (—) both of certain of the shrub species encountered in alternate 5×5 m quadrats and of the tree *Melaleuca quinquenervia*, scored in successive adjacent 10×10 m quadrats. Variation in floristic composition of the shrubs and understorey between alternate 5×5 m quadrats scored and between successive pairs of these quadrats is shown in the values of an index of floristic differences (see Figure 7). Variation of characteristics of the top 5 cm of soil below the litter layer is also shown. (For methods of soil analysis see Table 4. For abbreviations of plant communities see Table 2).

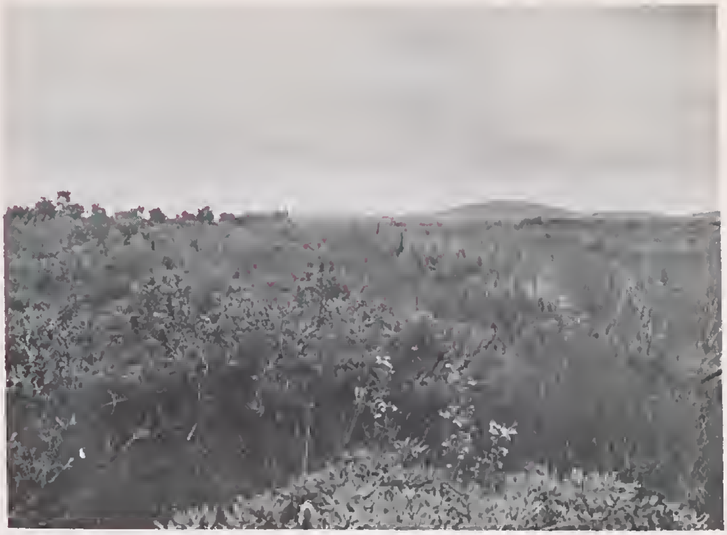

Figure 21. Wet Heath on differentiated Inner Barrier (Pib) about 1.5 km northwest of Big Gibber. *Xanthorrhoea resinosa* ssp. *fulva*, *Banksia oblongifolia* and *Leptocarpus tenax*. To the left Dry Heath with *Banksia aemula*, and to the right a narrow band of Swamp with *Callistemon citrinus*.

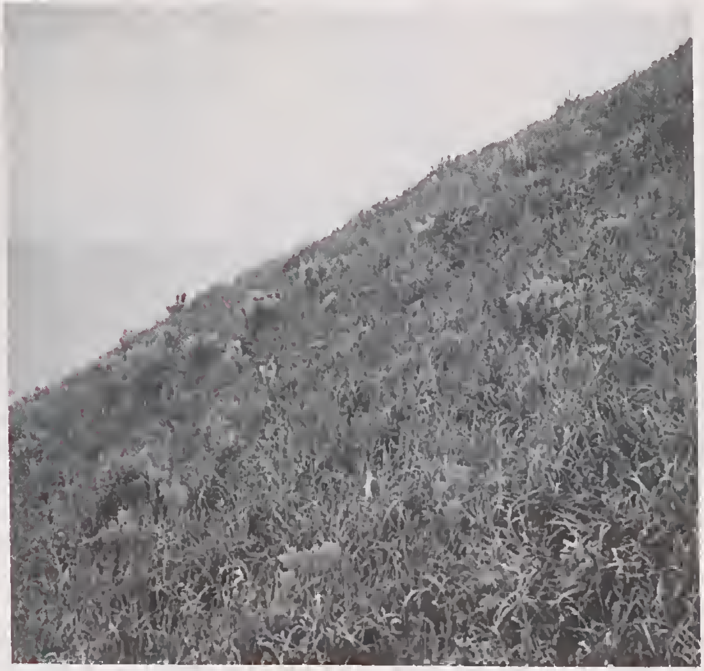

Figure 22. Sand Grassland about 350 m north of the northern end of Number One Beach, Seal Rocks. *Imperata cylindrica*, *Lomandra longifolia*, *Actinotus helianthi*, *Correa alba*, *Pteridium esculentum*.

northeasterly winds. In some sites where it abuts Dry Sclerophyll Forest there are dead *Eucalyptus pilularis* trees present, indicative of a recent extension of Sand Grassland into the edge of the Dry Sclerophyll Forest. Given a sufficiently long period free from fire, the woody plants within it would probably grow up to form a wind-pruned canopy.

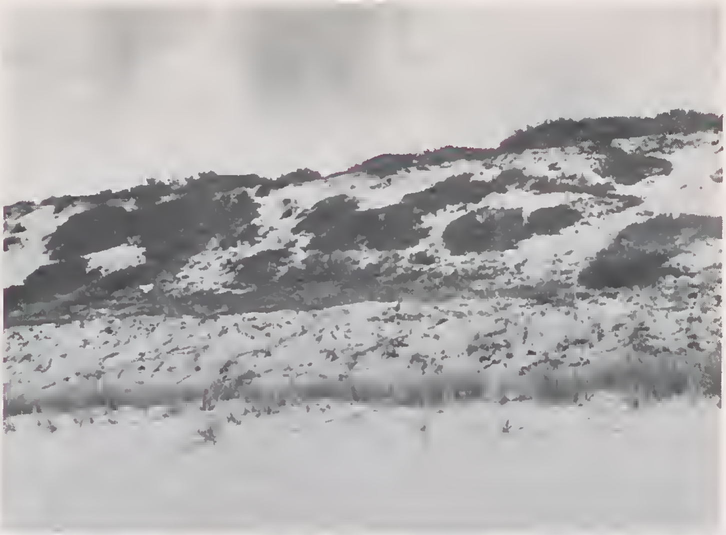

Figure 23. Foredune Complex south of Bombah Broadwater on two berms and cut face of dune. More seaward berm with *Spinifex hirsutus, Senecio lautus* ssp. *maritimus.* More landward berm with *Spinifex hirsutus, Senecio lautus, Scaevola calendulacea.* Cut face of dune with *Scaevola calendulacea, Hibbertia scandens, Euphorbia spormannii,* and at the top *Leptospermum laevigatum.*

FOREDUNE COMPLEX (Figure 23)

Here, shrubs and herbs are more or less at the same stratum level, and no species shows a particular dominance except in specific zones. The Foredune Complex occurs at the berm and on the steep seaward dune scarp over the crest of which it gives way to Beach-dune Thicket. Three zones can be delimited within the Foredune Complex: (1) the scarp face, where *Spinifex* and *Hydrocotyle* occur with other species; (2) the berm, where *Spinifex* and *Hydrocotyle* predominate and; (3) the *Cakile* zone seaward of the berm.

The steep scarp, with sand frequently close to the angle of repose, results from episodes of undercutting of the dunes by the sea and usually has a sparse cover of plants with much bare sand between them. Although such plants include *Scaevola calendulacea* and *Senecio lautus* ssp. *maritimus,* which accumulates sand and forms low hummocks (Osborn & Robertson, 1939), little sand accumulation occurs on the face.

The berm, which disappears during episodes of undercutting, is also frequently disturbed during winter storms, while the *Cakile* zone on the strand-line is even more frequently disturbed.

The community appears to be largely equivalent to Anderson's (1973) Sandy Foredune Association (fd. 1).

SWAMP (Figure 24)

Small tree and shrub stratum: absent or a few *Melaleuca quinquenervia* and *Banksia robur.*

"Herb" stratum: *Schoenus brevifolius, Restio complanatus, Lepyrodia muelleri, Baumea rubiginosa, Utricularia spp.*

Soils: usually more or less peaty with high loss on ignition.

Swamp, equivalent to the Sedge Swamp association of Anderson (1973), occurs in the in-filled inter-Barrier lagoon. It consists largely of restionaceous and cyperaceous species with *Empodisma minus* tending to form hummocks that Wet Heath species may colonize.

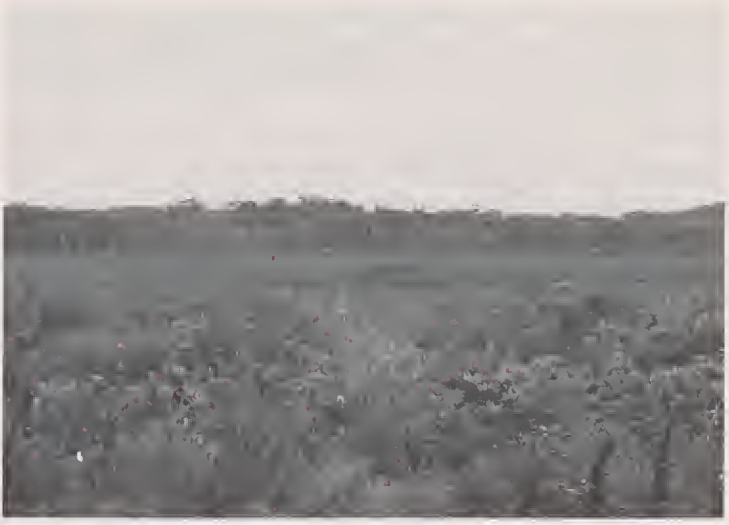

Figure 24. Swamp at eastern end of inter-Barrier lagoon (Pil). *Restio* spp., *Schoenus* spp., *Baumea* spp., *Gahnia sieberiana*, with Dry Heath in foreground.

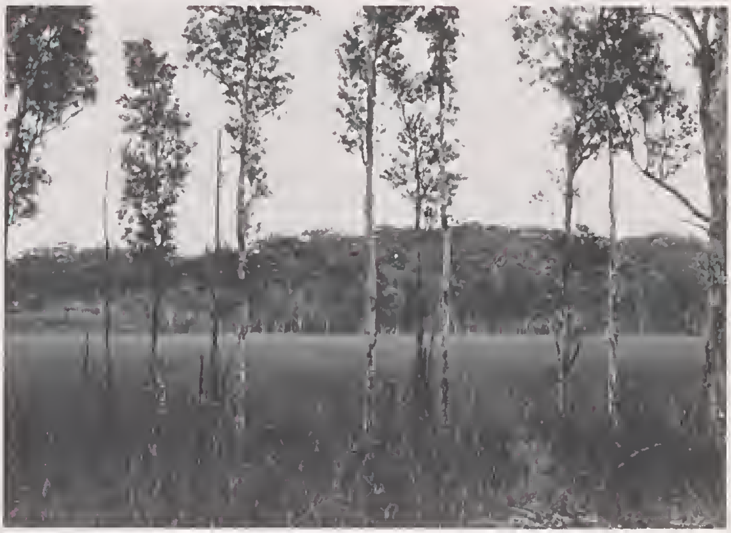

Figure 25. *Lepironia* Swamp in Glacial dune complex (Pg) east of Bombah Broadwater. *Lepironia articulata*, *Villarsia exaltata*, *Lepidosperma longitudinale*, with fringing *Melaleuca quinquenervia* in the foreground.

Gymnoschoenus sphaerocephalus is common in extensive areas of Swamp near Horse Point and forms steep-sided hummocks by the upward growth of its tussocks. It is not common in Swamp elsewhere in the area. Stunted specimens of *Melaleuca quinquenervia* are thinly scattered through the community, but *Eucalyptus robusta* appears not to occur in Swamp proper.

Swamp also occurs throughout the differentiated Inner Barrier where conditions are suitable, but mostly these areas are too small to map at the scale of 1:25 000. There are also other, more extensive areas of Swamp in the Eastern Lagoon and on low-lying ground south and east of Horse Point. Swamp mostly grades rather gradually into Swamp Forest, and has a somewhat deeper water-table than Swamp Forest.

The surface level in the Eastern Lagoon appears to be such that many Swamp and Wet Heath species can tolerate the conditions, and its vegetation is mapped here as a mixture of two communities. Such a mixture does not occur extensively elsewhere.

LEPIRONIA SWAMP (Figure 25)

"Herb" stratum: *Lepironia articulata.*

Soils: organic muds.

The dominant plant often occurs in Fringe Forest, but this community neither fringes the lakes nor contains either species of the dominant Fringe Forest trees. Only three areas are known: the two near Smiths Lake are flanked by Dry Sclerophyll Forest at the foot of the steep landward scarp of the Holocene transgressive dunes and by Dry Heath Forest along their northwestern sides; the third, near Broadwater, is mainly surrounded by Dry Sclerophyll Forest. Consisting almost entirely of open stands of *Lepironia articulata* in permanent standing water to c. 1 m deep, the community also contains *Lepidosperma longitudinale* in shallower water at the swamp near Bombah Broadwater.

DISCUSSION

Vegetation and land systems

The plant communities of the Eurunderee area are related in their occurrence to characteristics of the land systems (Table 5).

The rock-based land system is mostly clearly differentiated in its vegetation from the sand-based land systems. There are, however, two situations in which differences in vegetation between sand and rock-based parent materials are not clear-cut. The first is at the lake edges where Fringe Forest occurs on both rocky and sandy shores, though, as mentioned earlier, there tends to be a higher proportion of *Casuarina glauca* than *Melaleuca quinquenervia* in the trees on rocky shores, and conversely on sandy and muddy shores a higher proportion of *Melaleuca quinquenervia.* The second is in the occurrence of a thin layer of Holocene sand over rock in some small areas near Seal Rocks, where rainforest species and species characteristic of Dry Sclerophyll Forest and Beach-dune Thicket occur together. The vegetation of such ecotonal sites has been mapped here as Dry Sclerophyll Forest but Clough (1979) recognized some of them as rainforest.

The land systems on sand vary in vegetation with differences in soils, which are related to the age, mode of origin and topography of the surfaces. The Holocene sands vary less in vegetation than the Pleistocene sands. On the Pleistocene sands the vegetation varies in structure from forest to heath and sedgeland, often with relatively minor topographic variation. The structure of the vegetation on Holocene sands varies from the open herbfield and grassland of the Foredune Complex of the beach-front to forest inland, but inland there is little change in structure of the forest with major topographic variation. Only in a few depressions that are at or below the level of the water-table does Dry Sclerophyll Forest give way to Swamp Forest or in one area, where deep water collects, to *Lepironia* Swamp. On the low-lying lake-influenced sediments, Dry Sclerophyll Forest on freely drained sand gives way to Swamp or Swamp Forest in waterlogged sites, or to Fringe Forest on the lake shores themselves.

Between the Holocene and Pleistocene sands the boundaries in vegetation are mostly very sharp, particularly where the high Holocene dunes encroach on low-lying Pleistocene surfaces (e.g., Figure 8). However, there are some areas of sand close to rock on Bridge Hill and on Horse Point that carry Dry Sclerophyll Forest that adjoins Intermediate Dry Forest or Dry Heath Forest. Some of these sands carrying Dry Sclerophyll Forest that have been assigned to the Holocene may, in fact, be Pleistocene sand surfaces.

TABLE 5

Summary of occurrence of communities in the Eurunderee land systems

Land		Communities*
System	sub-system (symbol in Figure 1)	
Rock	(i) Inland (Ri)	(RF), WSF
	(ii) Headland (Rh)	HT, (VT)
Pleistocene sand	(i) Perched dune (Ppd)	(DHF) DH
	(ii) Early Inner Barrier (Pu)	(DSF), DHF, WHF, SF WH S
	(iii) Inner parabolic dunes (Pip)	(DSF), IDF, DHF, WHF, SF, WH S [c]
	(iv) Differentiated Inner Barrier (Pib)	((DSF)), DHF, (WHF), SF DH, WH S [c]
	(v) Undifferentiated Inner Barrier (Pub)	IDF, DHF, WHF, SF WH S
	(vi) Glacial dune complex (Pg)	DSF, IDF, DHF, SF WH S, LS
	(vii) Probable re-exposed surface (?P)	WHF, SF WH S
	(viii) Inter-Barrier lagoon (Pil)	SF ((DH)), WH S
Holocene sand (Outer Barrier)	— (H)	DSF, SF BT, SG, FC, (LS)
Lake-influenced sediments	(i) Lake silts and current lake shores (Ls)	SF, FF S
	(ii) Relict sand-bars (Lb)	DSF
	(iii) Sand of probable fluvial (and lacustrine) origin (Li)	DSF

*full names of communities are given in Table 2; ( ) = of rare occurrence; (( )) = isolated patch only; [c] = catenary sequences of communities common.

As indicated, the Pleistocene sands have the greatest variation in vegetation of any of the three land systems on sand in the Eurunderee area, both structurally and floristically. This can be related to the range of soil conditions that occur. The soils on these sands are all well developed, but vary with age of the surface, degree of nutrient enrichment from the surrounding areas, and with drainage.

Drainage is particularly important across the low-lying ground of all the Pleistocene surfaces except for what is probably the oldest surface, the aeolian perched dune on the northern side of the Big Gibber, and the youngest, the aeolian Glacial dune complex east of Bombah Broadwater. These two surfaces are raised above the general level of the other Pleistocene surfaces. On these other, low-lying surfaces, sequences of soils and vegetation occur in relation to drainage and height above the water-table. These catenary sequences are particularly well developed in the inner parabolic dunes and across the ridges and swales of the differentiated Inner Barrier. The following sequences are commonly found as the ground surface drops from a freely drained ridge to nearer the water-table in a swale—in the soils: podzol, humus podzol to swamp soil; and correspondingly, in the vegetation: Dry Heath Forest or Dry Heath, Wet Heath, to Swamp or Swamp Forest.

Nutrient enrichment of the characteristically infertile soils of the Pleistocene sands by run-off from surrounding rock-based sites seems to be apparent in parts of the inner parabolic dunes, where Dry Sclerophyll Forest, Intermediate Dry Forest or certain facies of Wet Heath Forest occur. In parts of the undifferentated Inner Barrier, particularly the Eastern Lagoon, there is some clay and silt with the sands, and the higher proportion of certain species such as *Hakea teretifolia* in the vegetation here than elsewhere may be related to this.

Ages of the Pleistocene sands in the Eurunderee area range from perhaps 500 000 to approximately 20 000 years before present (Thom, Bowman & Roy, 1981), and the degree of development of soils and types of vegetation they carry vary accordingly. Both the oldest, the perched dune on the Big Gibber, and the youngest surface, the Glacial dune complex east of Bombah Broadwater, are aeolian in origin, as are the inner parabolic dunes, which were laid down about 125 000 years ago. The oldest, the perched dune, has a particularly well developed podzol with deep B horizons. Its predominant vegetation is Dry Heath while the predominant vegetation of freely drained sites on the two younger aeolian Pleistocene sands is forest; on the inner parabolic dunes predominantly Dry Heath Forest and locally Intermediate Dry Forest; and on the Glacial dune complex predominantly Intermediate Dry Forest and locally Dry Sclerophyll Forest. On the Holocene aeolian sands of the Eurunderee area, there is only Dry Sclereophyll Forest on freely drained sites away from the sea. Data in Thom, Polach & Bowman (1978), Thom, Bowman & Roy (1981) and in Thom *et al.* (1981) indicate that most of the Holocene sands at the surface in the Eurunderee area have been deposited less than 3 500 years ago. In the Eurunderee area, with increasing age of freely drained aeolian surfaces, there is thus a sequence in the soils and vegetation, from very recently stabilized surfaces carrying Beach-dune Thicket with minimal soil development, to Dry Sclerophyll Forest on Holocene sands with incipient podzols further inland, to Intermediate Dry Forest on podzols on the Glacial dune complex, to Dry Heath Forest on podzols on the inner parabolic dunes, to Dry Heath on the perched dune with its deep podzols. The sequence in vegetation (Figures 3 & 4) is related to development and depth of the podzols.

There is no corresponding age sequence of beach ridges in the Eurunderee area. The differentiated Inner Barrier is the only well developed system of beach ridges occurring in the area. Beach ridges of similar age, about 125 000 years before present, occur nearby in the valley of the Upper Myall River and immediately southwest of the study area in the Fens Embayment. Also in the Fens Embayment there are Holocene beach ridges that, on data presented in Thom, Polach & Bowman (1978) and Thom *et al.* (1981), were laid down between about 5 000 and 3 500 years ago. They are thus older than the aeolian Holocene dunes of the Eurunderee area. They have podzols with B horizons at about 2 m deep and carry predominantly heath (Clements, pers. comm.). This heath is similar to the Dry Heath of the Eurunderee area with *Banksia aemula* and *Leptospermum attenuatum* occurring in some abundance, but differs in having relatively high amounts of *Casuarina distyla*. The Pleistocene beach ridges in the Fens Embayment carry a similar range of vegetation to those in the Eurunderee area but do have some MATK:D *Eucalyptus signata. E. signata* is absent from the differentiated Inner Barrier but does not occur very locally on areas of the undifferentiated Inner Barrier on the peninsula south of Pigeon Point, and there are a few isolated trees on Pleistocene sands immediately east of Bombah Broadwater.

The presence of heath and podzols on the Holocene beach ridges in the Fens Embayment is perhaps puzzling. It may indicate that podzolization and decline of fertility may be inherently more rapid on sands of beach ridges than on aeolian sands. In favour of this, it could be argued that plants on beach ridges have a smaller rooting volume available to them above the water-table than do plants growing on aeolian dunes, and thus a smaller "working capital" (term of Beadle & Burgess, 1949) of nutrients initially available to them. Loss of nutrients from this working capital may rapidly reduce it below the thresholds at which podzols readily develop and development of heath is strongly favoured. Furthermore, it could be argued that such loss of nutrients would be accelerated by frequent firing, and that this could have occurred on these beach ridges as they lie between the sea and the Lower Myall River along which Aborigines could have been expected to spend much time.

Taking beach ridges in the Eurunderee area, the valley of the Upper Myall River and the Fens Embayment, it seems that the forest becomes more common on freely drained sites the more inland they are, the higher above the water-table and the more sheltered they are by surrounding higher ground. Relationships between types of vegetation on beach ridges in the Fens Embayment are currently being studied by Clements and in the valley of the Upper Myall River by Carolin and Myerscough.

Vegetation of Eurunderee and other areas of coastal sand.

The Eurunderee area is important in the interpretation of vegetation on Holocene and Pleistocene sands on the eastern coast of Australia. The Pleistocene and Holocene sand masses are well developed and clearly differentiated in the Eurunderee area, and characteristic types of vegetation are associated with them. South of Newcastle to Jervis Bay, the only Pleistocene coastal sands are in small areas of wind-blown sand perched on cliff tops and headlands (Chapman *et al.*, 1982). South of Jervis Bay to the Victorian border, the only coastal sands that occur are Holocene, while on the northern coast of New South Wales, southeastern coast of Queensland and the dune islands off that coast, Pleistocene sands are extensive and Holocene deposits are in comparison limited in extent and development (Chapman *et al.*, 1982).

On the Holocene sands, the vegetation that has the greatest similarity between different parts of the eastern coast of Australia is the Foredune Complex. The Foredune Complex in the Eurunderee area is very similar to that described for the central (Pidgeon, 1940) and south coasts (Austin & Sheafe, 1976; Ingwersen, 1976) of New South Wales. It is also similar to that described for the north coast of New South Wales (Heyligers *et al.*, 1981) and, though it lacks some more tropical species such as *Ischaemum triticeum*, it is similar to that described for the coast of southeastern Queensland (Blake, 1938; 1968; Herbert, 1951) and for North Stradbroke Island (Clifford & Specht, 1979) and Moreton Island (Durrington, 1977). The similarities of vegetation of the Foredune Complex on the coast of eastern Australia are broadly outlined in Table 23.3 of Beadle (1981). Along the eastern coast of New South Wales, the Foredune Complex appears to be highly susceptible to invasion by *Chrysanthemoides monilifera.*

Beach-dune Thicket, as recognized here in the Eurunderee area, is less uniform in subtropical areas along the eastern coast of Australia. In southeastern Queensland, although *Banksia integrifolia* remains an important component, species that do not occur as far south as the Myall Lakes area, such as *Pandanus pedunculatus* and *Casuarina equisetifolia* var. *incana,* are important in this type of vegetation (e.g., Blake 1968; Durrington, 1977) while others, such as

Leptospermum laevigatum, do not occur. On the north coast of New South Wales, the equivalent type of vegetation frequently has a component of rainforest species on the lee slopes of the frontal dunes (e.g., Heyligers *et al.*, 1981). Beach-dune Thicket of the Eurunderee area is typical of similar vegetation on the central (Pidgeon, 1940) and southern coasts (Austin & Sheafe, 1976; Ingwersen, 1976) of New South Wales, but it has a different complement of species from comparable vegetation on calcareous dunes on the Victorian coast bordering Bass Strait (Parsons, 1966), though both *Leptospermum laevigatum* and *Banksia integrifolia* occur in that vegetation (Parsons, 1966).

The forest characteristic of the Holocene sands of the Eurunderee area, termed Dry Sclerophyll Forest in this study, clearly belongs to the *Eucalyptus pilularis—Angophora costata* Suballiance of the *Eucalyptus pilularis* Alliance of Beadle (1981). Under Baur's (1965) system, Dry Sclerophyll Forest of this study mainly belongs to the Blackbutt-Bloodwood/Apple forest type, forest type no. 41 in the Blackbutt league, but pure stands of *Angophora costata* in it would fall into the Smoothbarked Apple-Banksia forest type, forest type no. 107 in the Scribbly Gum-Stringybark-Silvertop Ash league. Dry Sclerophyll Forest of the Eurunderee area, as defined in this study, appears to be confined to the lower north and central coast of New South Wales. On Moreton Island, the *Eucalyptus pilularis* open forest of Durrington (1977) has a degree of similarity, with *E. pilularis* as dominant and the occurrence of *Banksia serrata* in the understorey and *Pteridium esculentum* and *Imperata cylindrica* in the ground layer, but it contains a number of tree and other species which are not part of Dry Sclerophyll Forest of the Eurunderee area. On the south coast of New South Wales, the forests developed on Holocene sands usually have SECAD *Eucalyptus botryoides* with or without *E. pilularis* and include the *Eucalyptus botryoides, Eucalyptus pilularis* and mixed *E. botryoides–E. pilularis* forests of Ingwersen (1976), the *E. botryoides–Banksia* spp. and *E. pilularis–E. botryoides* communities of Austin & Sheafe (1976), and the Bangalay-Banksia forest type (no. 108) of Baur (1965). In their understorey *Banksia serrata, Pteridium esculentum* and *Imperata cylindrica* are prominent components, as they are in the forest on Holocene sands at Wonboyn south of Eden beyond the geographical range of *E. pilularis.*

The plant communities on the Pleistocene sands of the Eurunderee area are part of the range of vegetation found on the Pleistocene sands between Sydney and Fraser Island. South of Newcastle, the areas of Pleistocene sands are mostly on cliff tops and carry heath dominated by *Banksia aemula*, as described in Bouddi National Park by Siddiqi, Carolin & Anderson (1973), very similar to Dry Heath of the Eurunderee area. These dry heaths and similar ones of Pleistocene sands of northern New South Wales (Benson, 1976; Heyligers *et al.*, 1981) and North Stradbroke Island (Clifford & Specht, 1979; Specht, 1979b), Moreton Island (Durrington, 1977) and presumably other parts of the coast of southeastern Queensland fall into *Banksia serratifolia (aemula)* Alliance of Beadle (1981). The *Banksia aspleniifolia (oblongifolia)* and *Banksia robur* Alliances of Beadle (1981) cover Wet Heath as defined in the Eurunderee area. There are few heaths dominated by *Banksia oblongifolia* or *B. robur* on Pleistocene coastal sands south of Newcastle, but they are well developed on parts of the Inner Barrier systems of the Newcastle Bight and Fens Embayment (Clements, pers. comm.) and in suitable habitats on other areas of Pleistocene sands northwards along the coast of New South Wales, as at Angourie (Benson, 1976), into southern Queensland.

The forests and woodlands associated with the heaths on Pleistocene sands occur northward from the Newcastle Bight to Fraser Island. Those of the Eurunderee area do not fit readily into Beadle's (1981) alliances, but fall somewhat between his *Eucalyptus signata–E. intermedia–E. nigra* Suballiance of the *Eucalyptus intermedia–E. acmenoides–E. signata–E. nigra* Alliance, *Eucalyptus pilularis–Angophora costata* Suballiance of the *E. pilularis* Alliance, and his *Banksia serratifolia (aemula)* and *Banksia aspleniifolia (oblongifolia)*

Alliances. Perhaps they are best regarded as more related to the two heath alliances than to the forest alliances, in which case Dry Heath Forest and Intermediate Dry Forest in the Eurunderee area should be related to the *Banksia serratifolia (aemula)* Alliance, and Wet Heath Forest to the *Banksia aspleniifolia (oblongifolia)* Alliance of Beadle (1981). The heath forests and woodlands of the Pleistocene sands of the Eurunderee area are closely related to those in similar habitats in northern New South Wales, as at Angourie (Benson, 1976) and in Bundjalung National Park (Heyligers *et al.*, 1981), and on the dune islands off the southern coast of Queensland, on Moreton Island (Durrington, 1977) and North Stradbroke Island (Clifford & Specht, 1979), particularly in the understorey, but they lack some tree species such as CAFID *Eucalyptus intermedia*, MAIBB *E. planchoniana*, AAACA *Angophora woodsiana* and *Callitris columellaris* and some understorey species such as *Strangea linearis*, the southern limits of whose distributions on the coast lie north of the Myall Lakes area.

The heaths and associated forests and woodlands of the Pleistocene sands of the central and northern coast of New South Wales and the southeastern coast of Queensland and its off-shore dune islands form a closely related complex of plant communities, which are clearly different from those on Pleistocene coastal sands in northern Queensland, as described by Pedley & Isbell (1971), Specht (1979b) and Pyke & Jackes (1981).

Swamp and Swamp Forest of the Eurunderee sand mass are similar to those in wetlands on other coastal sands of northern New South Wales and southern Queensland. The Eurunderee Swamp Forest and Fringe Forest do not fit easily into the *Eucalyptus robusta* Alliance of Beadle (1981), nor do Swamp or *Lepironia* Swamp fit well into his *Calorophus minor* (*Empodisma minus*)–*Leptocarpus tenax* Alliance. The Eurunderee Swamp is clearly closely related to coastal bogs of Goodrick (1970). Communities similar to the Eurunderee Swamp and Swamp Forest occur very locally on coastal sands south of Newcastle as far as the Tuggerah Lakes, but occur more extensively on coastal sands on the north coast of New South Wales and in southern Queensland, as on Moreton Island (Durrington, 1977). *Lepironia* swamps are distinctive and occur on coastal sands in northern New South Wales (Goodrick, 1970; Heyligers *et al.*, 1981) and in southern Queensland, as on Moreton Island (Durrington, 1977).

Quaternary changes and vegetation of coastal sands of northern New South Wales and southern Queensland.

As indicated above, the Eurunderee sand mass is part of a complex of Pleistocene and Holocene coastal sands stretching from Newcastle to the coast of southern Queensland and the dune islands lying off it. The bedrock of this part of the coast has apparently been remarkably stable tectonically during the Quaternary and, accordingly, present levels of Pleistocene and Holocene sand sheets directly reflect the original levels at which they were deposited on the coast. This complex of coastal sands north from Newcastle to Fraser Island is distinctive geomorphologically, and, as shown above, its vegetation, particularly on its Pleistocene sands, forms a distinctive unit, clearly differentiated from the vegetation on old coastal sands in tropical Queensland and from that on the Holocene sands of the coast south of Sydney.

The vegetation of coastal sands along this portion of the eastern coast was obviously more extensive when sea level was lower than at present, and less extensive approximately 125 000 years ago when the sea level was higher and the shores farther inland than at present. In the Eurunderee area 125 000 years ago there were possibly few stabilized sand sheets with podzols, with the probable exception of wind-blown sands in place on the lee side of the Big Gibber and possibly other headlands. Such areas could have provided refugia for species such as *Banksia aemula* which now rarely occur off highly podzolized sands. Failing the availability of local refugia, such species may have migrated south from refuges on podolized sands on the 'Ancient Dunes' of North Stradbroke Island and other dune islands off southern Queensland. Such southward migration would probably have occurred most readily during glacial periods when sea levels were low and extensive sand sheets were exposed to seaward of present shore lines. Also, over spans of time of 100 000 years the possibility of appreciable genetic change and associated change of occupancy of habitats on species cannot be ruled out.

During 100 000 years or more of exposure, appreciable podzolization of Pleistocene sands has occurred, and it has been suggested that nutrient stocks in such sands have been depleted and this has influenced the sort of vegetation they carry. Circumstantial evidence for this suggestion comes from four sources: the degree of podzolization evident; the type and structure of the vegetation present; estimates of nutrient stocks in the system; and attributes of plants in the vegetation.

On the degree of podzolization evident, on raised wind-blown sand surfaces at Cooloola, Thompson (1981) and Walker *et al.* (1981) concluded that with increasing age of the surface the depth to the B horizons increases and the amounts of total phosphorus and potassium in the surface layers of the soil decreases. The Eurunderee area is without such a comprehensive sequence of wind-blown sands of various ages and sufficient relief to allow control of the depth of B horizons other than by water-table. The Pleistocene dunes perched on the Big Gibber alone are of sufficient relief, and contrast sharply in their deep, highly developed podzols and Dry Heath vegetation with the adjoining wind-blown Holocene dunes carrying Dry Sclerophyll Forest on incipient podzols in which the B horizon is at most only about 1.5 m deep.

On the type and structure of vegetation present, Westman (1978) has suggested that on North Stradbroke Island the decrease in stature of forest on older dunes deposited 500 000 or more years ago may be due to loss of nutrients from the systems, particularly potassium and phosphorus. At Cooloola, Walker *et al.* (1981) showed that height, structure and estimated biomass of the vegetation increased initially with age of the sands from a type of beach-dune thicket to tall layered forest, and thereafter declined with age until on the oldest surfaces the vegetation is predominantly shrubs with little tree crown cover. They attribute this pattern to an initial increase in the working capital of nutrients brought into circulation by weathering of minerals in the soil, and then following the complete release by weathering of all nutrients in the rooting zone, a subsequent run-down of the working capital, with losses of nutrients in leaching not being entirely balanced by gains in rainfall and dry deposition from the atmosphere. The nutrient balance of forest dominated by *Eucalyptus signata* on Pleistocene dunes on North Stradbroke Island has been shown by Westman (1978) to be partly dependent on inputs of nutrients in rain and salt spray. In the Eurunderee area, a sequence of vegetation types similar to that found at Cooloola by Walker *et al.* (1981) can be seen with age of surfaces on wind-blown sands, passing from Beach-dune Thicket to tall Dry Sclerophyll Forest on the high Holocene dunes, to the lower, more open tree canopy of Intermediate Dry Forest on the Glacial dune complex, to the yet more open and lower tree canopy of Dry Heath Forest on the Pleistocene inner parabolic dunes, and finally to Dry Heath on the Pleistocene perched dune on the Big Gibber. As suggested earlier, progression through such a sequence may be accelerated on low beach ridges where the position of the B horizon is controlled by the shallow water-table, the rooting zone for the plants is more restricted, and therefore the potential pool of nutrients is likely to be much more limited than in wind-blown sands in high dunes. In addition, repeated fires may pass more frequently and burn more intensely over a terrain of low beach ridges and may further accelerate depletion of the limited nutrient stocks. Certainly, heaths are widespread on the Pleistocene beach ridges in the Eurunderee area and also on the early Holocene beach ridges in the Fens Embayment. These heaths on beach ridges are comparable to the pygmy forests in California on highly podzolized sands over shallow water-tables, described by Westman (1975) and Westman & Whittaker (1975).

Nutrient stocks are thus seen as crucial in the above hypothetical schemes of vegetational change with age of the sand surfaces. Clearly the schemes would be on firmer ground if comparative data on total nutrient stocks were available from sand systems of a range of ages. To date, there have been only two studies of nutrient stocks in systems on coastal sands between Newcastle and Fraser Island. One study, that of Westman & Rogers (1977), was in a forest dominated by *Eucalyptus signata* on a younger Pleistocene dune on North Stradbroke Island. The other was in the Eurunderee area by Lewis (1978) in Dry Sclerophyll Forest on Holocene dunes of the Outer Barrier southwest of the Big Gibber. The nutrient stocks per unit area of ground in the biomass and dead material were determined in comparable ways in the two studies, but those in the soil were not. The stocks of potassium and calcium in the biomass and litter were similar in both sites. Magnesium in the biomass at the North Stradbroke site was approximately a third that at the Eurunderee site as was the stock of nitrogen in the biomass. The most striking difference between the two sites was in the stocks of phosphorus in the biomass and litter. At the North Stradbroke site the stock of phosphorus in the litter was about a third of that in the dead material at the Eurunderee site, while in the biomass the stock of phosphorus at the North Strtadbroke site was only about 15 per cent of that at the Eurunderee site. Comparison of data from the two sites thus supports the notion that as the sand surface ages the stock of the key nutrient phosphorus becomes depleted, in accord with the hypothetical scheme proposed. However, this comparison between a forest on Holocene sand and one on a Pleistocene sand surface is confounded with the geographical separation of the sites between the Myall Lakes and North Stradbroke Island, and is incomplete in that stocks of nutrients in the soils of the two sites were not estimated on a sufficiently similar basis to allow comparison. Clearly, such a comparison of nutrient stocks between systems on sand surfaces of different ages would be far better made in the same geographical area.

Certain attributes of the plants on older sand surfaces can be related to the depletion of nutrient stocks that is hypothesized to have occurred under prolonged weathering of these surfaces. These attributes relate to economical usage, efficient uptake and retention of nutrients, especially phosphorus (Beadle, 1966; 1968; Jeffrey, 1967; Siddiqi & Carolin, 1976), and include the increasingly sclerophyllous nature of the plants apparent on progressively older sand surfaces, the increased tendency to form lignotuberous masses of tissue in the soil surface and increased resistance of mature individuals to elimination by fires and a related lower reproductive effort in seed production.

The increasingly sclerophyllous nature of the vegetation is apparent across the age sequence of wind-blown dunes in the Eurunderee area, where species with mesomorphic leaves are reasonably abundant in Beach-dune Thicket, but at the other end of the sequence in Dry Heath nearly all the species of plants present are markedly sclerophyllous. It has been cogently argued that plants with highly lignified leaves make sparing use of phosphate that is generally in short supply in their characteristic habitats (Loveless, 1961; 1962; Beadle, 1966; 1968).

The tendency of many plants in the Eurunderee Dry Heath Forest and Dry Heath to have large lignotuber-like organs has already been mentioned. In *Eucalyptus gummifera*, the mallee form that has large lignotuber-like organs with a capacity for storage of phosphate (Mullette, 1978) is particularly apparent in Dry Heath especially on the Big Gibber, whereas in its rare occurrence on the Eurunderee Holocene dunes *Eucalyptus gummifera* was almost entirely present in the form of a single-stemmed tree. Unfortunately, like the Pleistocene perched dune on the Big Gibber, the part of the Holocene high dunes carrying *E. gummifera* have had their original vegetation destroyed by sand mining over the last 10 years.

The increasing tendency for mature individuals to be long-lived, highly resistant to elimination by fire and to have relatively low seed reproduction on older sands can be seen in some closely related species. Thus, *Leptospermum laevigatum* is common in the Beach-dune Thicket of the Eurunderee area but does not usually occur in Dry Heath, while *L. attenuatum* occurs only on old, well podzolized sands. Many individuals of *L. attenuatum* survive through fires, while individuals of *L. laevigatum* are readily killed by fire (Burrell, 1981). Mature individuals of *L. laevigatum* usually carry a large crop of seeds in their canopies the whole year round, while those of *L. attenuatum* shed their seeds soon after fruits have ripened. In *Banksia* in the Eurunderee area, *B. integrifolia* is almost entirely confined to the Holocene sands and *B. aemula* to the Pleistocene sands. *B. serrata* is intermediate between the two in its occurrence, that is, on Holocene sands, but not as close to the shoreline as *B. integrifolia*, and only on Pleistocene sands where nutrient enrichment seems likely to have taken place or where the sand surface was laid down in the late Pleistocene, as in the Glacial dune complex. Mature individuals of *B. aemula* survive most fires, particularly in the lignotuberous form in which they occur in Dry Heath, and normally they carry a relatively small crop of seeds. In *B. integrifolia*, the mature individuals are relatively easily killed but produce large crops of seed which are shed annually. In *B. aemula* and *B. serrata*, the fruits are serotinous and normally only shed their seeds when the branch bearing them dies, which occurs when the mature plants are burnt. Mature plants of *B. serrata* appear to be somewhat intermediate between those of *B. integrifolia* and *B. aemula* in their resistance to fire and in their seed output. The relative seed weights in the species are graded from *B. integrifolia* with the lightest seeds to *B. aemula* with the heaviest seeds. Seeds of *B. aemula* have appreciable amounts of stored phosphorus (Grundon, 1972). Its heavier, well endowed seedlings may be expected to have a selective advantage over those of the other two species in the highly infertile sands in which *B. aemula* grows. The neatly graded series apparent in the Eurunderee area in the distribution of these three species of *Banksia* is not maintained on the Cooloola sands where *B. integrifolia* occurs on Pleistocene sands as well as younger sands, while *B. serrata* appears to be confined to younger sands (Walker *et al*., 1981). On North Stradbroke Island also, *B. integrifolia* occurs on Pleistocene as well as younger sands (Durrington, 1977). This suggests either that the attributes of the species may not be so readily linked to their distribution across a series of sands of increasing age, as they appear to be in the Eurunderee area, or that the attributes may vary somewhat between different parts of their geographical range.

The four strands of circumstantial evidence taken together—the attributes of the species in the types of vegetation, nutrient stocks in the systems, the types and structure of the vegetation, and the relative podzolization of the sands—make a reasonable argument for linking depletion of nutrient stocks to change of vegetation type with increasing age of the sand surfaces in wind-blown dunes. It also appears likely that old beach ridges present a situation in which the effective working capital of nutrients may be initially lower and consequent depletion of nutrients generates change from forest to heath more quickly than on aeolian dunes of the same elevation.

The sand masses of the Eurunderee area and their vegetation are significant as part of the complex of coastal sands and their associated vegetation that lie between Fraser Island and Newcastle, while the aeolian Holocene sands of the Eurunderee area are unique in southeastern Australia in their elevation, extent and form and in the extensive high Dry Sclerophyll Forest that has developed on what are relatively recently stabilized surfaces.

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APPENDIX 1

Myall Lakes Checklist

Some records of Pteridophytes are from Timms, B. & Timms, B. Ferns of Myall Lakes National Park. *Hunter Natural History*, 9, 74–88. Nomenclature of cycads and angiosperms largely follows Jacobs, S. W. L. & Pickard, J. (1981). *Plants of New South Wales: a census of the cycads, conifers and angiosperms.* Government Printer, Sydney. Authorities for names are only given where they differ from those in Jacobs & Pickard (1981).

sa = submerged aquatic
fa = floating aquatic
* indicates introduced species

Communities:

WSF	Wet Sclerophyll Forest	HT	Headland Thicket
DSF	Dry Sclerophyll Forest	VT	Vine Thicket
IDF	Intermediate Dry Forest	BT	Beach-dune Thicket
DHF	Dry Heath Forest	DH	Dry Heath
WHF	Wet Heath Forest	WH	Wet Heath
SF	Swamp Forest	SG	Sand Grassland
FF	Fringe Forest	FC	Foredune Complex
S	Swamp	LS	*Lepironia* Swamp

PTERIDOPHYTA

ADIANTACEAE	
Adiantum aetheopicum L.	WSF
A. hispidulum Swartz	WSF
Cheilanthes sieberi Kunze	WSF
ASPIDIACEAE	
Lastreopsis microsora (Endl.) Tindale	VT
ASPLENIACEAE	
Asplenium obtusatum Forst. f. var. *difforme* (R.Br.) Benth.	HT
AZOLLACEAE	
Azolla pinnata R.Br.	fa
BLECHNACEAE	
Blechnum camfieldii Tindale	S
B.cartilagineum Sweet	DSF,DHF,S,FF,WHF,SF,VT
B.indicum Burm.f.	S,SF,FF
Doodia aspera R.Br.	WSF,VT
CYATHEACEAE	
Culcita dubia (R.Br.) Maxon	WHF,DSF
DENNSTAEDTIACEAE	
Histiopteris incisa (Thunb.) Smith	WHF
Pteridium esculentum (Forst.f.) Cockayne	WSF,DSF,DHF,DH,WH,BT,HT,SG
GLEICHENIACEAE	
Gleichenia dicarpa R.Br.	WH,S,SF,WHF
LYCOPODIACEAE	
Lycopodium deuterodensum Hert.	WH,S,SF,WHF
L. laterale R.Br.	WH,S,SF,WHF
LYGODIACEAE	
Lygodium scandens (L.) Swartz	WH,WHF,S,SF
OSMUNDACEAE	
Todea barbara (L.) T. Moore	FF

POLYPODIACEAE	
Platycerium bifurcatum (Cav.) C. Chr.	FF
SCHIZAEACEAE	
Schizaea bifida Willd.	DHF,DH
SELAGINELLACEAE	
Selaginella uliginosa (Labill.) Spring	WH,S,SF,WHF
SINOPTERIDACEAE	
Pellaea falcata (R.Br.) Fée	WSF
THELYPTERIDACEAE	
Christella dentata (Forsk.) Brownsey & Jermy	WSF
Cyclosorus interruptus (Willd.) H. Ito	S
GYMNOSPERMAE	
ZAMIACEAE	
Macrozamia communis	DHF,DSF,IDF
ANGIOSPERMAE—MONOCOTYLEDONES	
ARECACEAE (PALMAE)	
Livistona australis	VT,DSF,SF
BURMANNIACEAE	
Burmannia disticha	SF
CENTROLEPIDACEAE	
Centrolepis strigosa	WH,S
COMMELINACEAE	
Commelina cyanea	WSF,DSF,IDF,HT,FC
CYPERACEAE	
Baumea articulata	SF,FF
B. arthrophylla	SF,FF,LS,WHF
B. muelleri	WH,S
B. juncea	SF,S,FF,SG
B. rubiginosa	WH,SF,S,WHF
Carex appressa	WSF,S,SF,VT
C. declinata	SF
C. longebrachiata	WSF,SF,FF,VT
C. pumila	FC
Caustis pentandra	DHF,DH
C. recurvata	DSF
Chorizandra cymbaria	WH,SF
C. sphaerocephala	WH,SF,S
Cladium procerum	FF
*Cyperus brevifolius**	WSF
C. gracilis	WSF,DSF,DHF,DH
C. polystachyos	FF
Gahnia aspera	WSF,DSF,VT
G. clarkei	WHF,SF,DHF
G. melanocarpa	WSF
G. sieberiana	WH,SF,FF,S
Gymnoschoenus sphaerocephalus	WH,S
Isolepis inundata R.Br.	SF,S,FF
I. nodosa (Rottb.) R.Br.	BT,HT,FC,SG
I. pachylepis S. T. Blake	WH
Lepidosperma flexuosum	WH
L. forsythii	WH
L. laterale R.Br.	DSF,DHF,DH,IDF,WH,SG
L. longitudinale	FF,LS
L. neesii	WH,S
L. quadrangulatum	SF
Lepironia articulata	SF,LS
Ptilanthelium deustum	DH,WH

Rhynchospora brownii	WSF
Schoenus brevifolius	WH,SF,S
S. ericetorum	DHF,DH,WH
S. maschalinus	WH,SF,FF,HT
Schoenoplectus litoralis (Schrad.) Palla	FF
S. validus (Vahl) A. & D. Löve	FF
DIOSCOREACEAE	
Dioscorea transversa	WSF,HT
ERIOCAULACEAE	
Eriocaulon scariosum	WH,SF,S,FF
HAEMODORACEAE	
Haemodorum corymbosum	DHF,DH,WH
H. planifolium	DSF,IDF,DHF
HYDROCHARITACEAE	
Vallisneria gigantea	sa
IRIDACEAE	
*Gladiolus gueinzii**	FC
Patersonia glabrata	DSF,DHF,DH
P. longifolia	WH
P. sericea	DHF,DH
*Romulea rosea**	WSF
*Sisyrinchium iridifolium**	WSF
JUNCAEAE	
*Juncus cognatus**	WSF,DSF
J. continuus	WSF,SF
J. kraussii	FF
J. planifolius	DSF
J. usitatus	WSF,BT
JUNCAGINACEAE	
Maundia triglochinoides	FF
Triglochin procera	sa,SF,S
LILIACEAE	
Blandfordia grandiflora	DHF,DH,WH
Burchardia umbellata	DHF,DH,WH
Dianella caerulea	DSF,DHF,DH,IDF,WHF,SG
D. laevis	WSF
Sowerbaea juncea	WH
Stypandra caespitosa	DSF
Tricoryne elatior	DSF,DHF,IDF,WH,WHF
LOMANDRACEAE	
Lomandra glauca ssp. *glauca*	DHF,DH,IDF
L. longifolia ssp. *longifolia*	WSF,DSF,DHF,IDF,WHF, FF,BT,HT,FC,SG
L. micrantha	DSF
L. multiflora	WSF
NAJADACEAE	
Najas marina ssp. *armata*	sa
ORCHIDACEAE	
Acianthus caudatus	DSF
Caladenia carnea	DSF
C. catenata (Smith) Druce	DHF, DH
Caleana major	DSF, DHF
Calochilus paludosus	DSF
Chiloglottis reflexa	DSF
Dendrobium teretifolium	FF
Dipodium punctatum	DSF
Diuris aurea	DHF, DH
Glossodia major	DHF, DH
G. minor	DSF,DHF,DH

Lyperanthus suaveolens	DSF
Pterostylis nana	DSF
P. nutans	DH
POACEAE (GRAMINEAE)	
Agrostis avenacea	WSF,DSF,DHF,DH,IDF
Anisopogon avenaceus	DSF,DHF,DH,IDF,HT
*Axonopus affinis**	WSF,DSF
*Chloris gayana**	FC,HT
*Cortaderia selloana**	DH,WH
Cymbopogon refractus	WSF,DSF, BT,HT,FC,SG
Cynodon dactylon	WSF,DSF
Danthonia tenuior	WSF
Dichelachne crinita	DSF,DHF,BT,FC
D. micrantha	WHF
Digitaria parviflora	WSF,DSF
*Echinochloa crus-galli**	WSF
Echinopogon ovatus	WSF,DSF,DHF,IDF,HT
*Ehrharta erecta**	DSF
Entolasia marginata	WSF,DH,IDF,WH
E. stricta	DHF,DH
Eragrostis brownii	WSF,DSF,DHF,DH,SG
E. elongata Jacq.	DSF,DHF,DH
Eriachne pallescens	DH
Hemarthria uncinata	S
Imperata cylindrica	WSF,DSF,DHF,IDF,WHF,SG,HT,BT
Ischaemum australe	WSF,DSF
Microlaena stipoides	WSF
Oplismenus aemulus (R.Br.) Kunth	WSF
O. imbecillis	SF,HT
Panicum simile	DSF,DHF,DH,IDF,SG,WHF
*Parapholis incurva**	WH
Paspalidium aversum	DSF
P. radiatum	DSF
*Paspalum dilatatum**	WSF,DSF,HT
P. orbiculare	WSF,DSF
*Pennisetum cladestinum**	HT
Phragmites australis	FF
Plinthanthesis paradoxa	WSF,DSF,DHF,DH
Poa labillardieri	WSF
P. poiformis	SG
Pseudoraphis paradoxa	WH
Spinifex hirsutus	FC
*Sporobolus africanus**	WSF,DSF
*Stenotaphrum secundatum**	WSF
Themeda australis	WSF,DSF,DHF,DH,IDF,WHF,SG,HT
*Vulpia bromoides**	SF,WSF,DSF,FF,HT,FC
Zoysia macrantha	BT,HT,FC,SG
PHILESIACEAE	
Eustrephus latifolius	WSF,DSF
Geitonoplesium cymosum	WSF,DSF
POTAMOGETONACEAE	
Potamogeton pectinatus	sa
P. perfoliatus	sa
P. tricarinatus	sa
RESTIONACEAE	
Coleocarya gracilis	DHF,IDF
Empodisma minus	WH,SF,S,WHF
Hypolaena fastigiata	DHF,DH,IDF
Leptocarpus tenax	DHF,DH,IDF,WH,WHF,S
Lepyrodia interrupta	DH,WH,WHF
L. gracilis	WH
L. muelleri	SF,S
L. scariosa	WH,WHF

Restio complanatus	WH,S
R. pallens	WH,WHF,SF,S
R. tetraphyllus ssp. *meiostachyus*	DSF,DHF,DH,WH,WHF,SF,S
RUPPIACEAE	
Ruppia megacarpa	sa
SMILACACEAE	
Smilax australis	HT,VT
S. glyciphylla	WSF
TYPHACEAE	
Typha orientalis	FF
XANTHORRHOEACEAE	
Xanthorrhoea australis ssp. *australis*	DSF,DHF,DH,IDF,WH,WHF
X. macronema	WSF,WHF
X. media ssp. *latifolia*	WSF
X. resinosa ssp. *fulva*	WH,WHF
XYRIDACEAE	
Xyris gracilis	WH
X. juncea	WH,WHF
X. operculata	WH
ZOSTERACEAE	
Zostera capricorni	sa
DICOTYLEDONES	
ACANTHACEAE	
Brunoniella australis	WSF
Pseuderanthemum variabile	WSF
AIZOACEAE	
Carpobrotus glaucescens	BT,HT,FC
Macarthuria neocambrica	WH
APIACEAE (UMBELLIFERAE)	
Actinotus helianthi	DSF,DHF,DH,SG,IDF
A. minor	DH,WH
Centella asiatica	S
Hydrocotyle acutiloba (F.Muell.) Wakefield	WH,SF,BT,FC
*H. bonariensis**	BT,HT,FC
H. tripartita	HT
Lilaeopsis polyantha	FF
Platysace ericoides	DSF,IDF
P. lanceolata	DSF,DHF,DH,IDF
P. linearifolia	DHF,DH,IDF
Trachymene incisa	DHF,DH,IDF
Xanthosia pilosa	DHF,DH,IDF
APOCYNACEAE	
Parsonsia straminea	WSF,VT
ARALIACEAE	
Astrotricha longifolia	WSF,DSF,SG.
Polyscias sambucifolia	WSF,DSF
ASCLEPIADACEAE	
*Araujia hortorum**	WSF,HT
ASTERACEAE (COMPOSITAE)	
*Ageratina adenophora **	WSF,SG
*Aster subulatus**	FF
*Bidens pilosa**	WSF
Cassinia aculeata	DSF,DHF
Chrysanthemoides monilifera ssp. *rotundata**	FC
*Cirsium vulgare**	WSF,DSF
*Conyza canadensis**	WSF,DSF,BT,HT,FC,SG
Cotula coronopifolia	FF
C. longipes	FF
Gnaphalium involucratum	DSF,FC

*G. purpureum**	DSF
Helichrysum bracteatum	SG
*Hypochoeris radicata**	WSF,DSF,DHF,DH,IDF,WH, FF,BT,HT,FC
Melanthera biflora	VT
*Picris hieracioides**	WSF
Pseudognaphalium luteoalbum (L.) Hilliard et Burtt	DSF,FF
Senecio lautus ssp. *dissectifolius*	WSF,DSF,SG
S. lautus ssp. *maritimus*	FC,SG
S. linearifolius	DSF,DHF
Sonchus megalocarpus (Hook.f.) J. M. Black	FC
BAUERACEAE	
Bauera rubioides	WH,WHF
BIGNONIACEAE	
Pandorea pandorana	DSF,BT,HT,FC,VT
BRASSICACEAE (CRUCIFERAE)	
Cakile edentula	FC
CAMPANULACEAE	
Wahlenbergia communis	WSF
W. gracilis	DSF,BT,HT,FC
W. stricta	WSF,DSF,HT
CASUARINACEAE	
Casuarina glauca	FF
C. littoralis	DSF,WSF
C. torulosa	WSF,DSF
CHENOPODIACEAE	
Rhagodia candolleana Moq.	FC
Sarcocornia quinqueflora	FF
CHLOANTHACEAE	
Chloanthes stoechadis	DSF,DHF
Spartothamnella juncea	WH,SF,S
CONVOLVULACEAE	
*Ipomoea cairica**	FC
Polymeria calycina	WH
CUNONIACEAE	
Ceratopetalum apetalum	VT
Schizomeria ovata	VT
DILLENIACEAE	
Adrastaea salicifolia	DSF,DHF,IDF,SG
Hibbertia fasciculata	DHF,DH
H. linearis	DSF
H. nitida	DH
H. obtusifolia	DSF,DHF,IDF,SG
H. scandens	WSF,DSF,WHF,IDF,BT,HT,FC,VT
DROSERACEAE	
Drosera binata	SF,S,FF
D. peltata	DHF,DH,WH
D. pygmaea	VT
ELAEOCARPACEAE	
Elaeocarpus obovatus	WSF
E. reticulatus	DSF
EPACRIDACEAE	
Astroloma pinifolium	DHF,DH
Brachyloma daphnoides	DHF,DH,IDF
Epacris microphylla	WH
E. obtusifolia	WH,S
E. paludosa	WH,S
E. pulchella	DHF,DH,IDF
Leucopogon ericoides	DSF,DHF,DH

L. lanceolatus var. *gracilis*	DSF,DHF,DH,IDF
L. muticus	DHF, DH
L. parviflorus	DSF,DHF,DH,FC
L. virgatus	DHF,DH
L. rodwayi	DHF,DH,IDF
Melichrus procumbens	DSF,IDF
Monotoca elliptica	DSF,IDF,SG
M. scoparia	DSF,DHF
Sprengelia incarnata	WH
S. sprengelioides	WH
Styphelia viridis	DHF,DH
Trochocarpa laurina	VT
Woollsia pungens	DSF,DHF,DH,IDF
EUPHORBIACEAE	
Amperea xiphoclada	DSF,DHF,DH,IDF
Baloghia lucida	VT
Breynia oblongifolia	DSF,BT,HT,SG
Euphorbia sparrmanii	FC
Glochidion ferdinandi	SF
Omalanthus populifolius	WSF
Phyllanthus thymoides	DSF,DHF,DH,IDF
Poranthera corymbosa	DSF,SG
P. ericifolia	DSF
P. microphylla	DH,HT
Pseudanthus orientalis	DSF,DHF,DH
P. pimeleoides	DH,WH
Ricinocarpos pinifolius	DSF,DHF,DH,IDF
EUPOMATIACEAE	
Eupomatia laurina	VT
FABACEAE (PAPILIONACEAE)	
Aotus ericoides	DSF,DHF,DH,IDF
Bossiaea ensata	DHF,DH,IDF,SG
B. heterophylla	DSF,DHF,DH,IDF
B. rhombifolia	DHF,DH
Chorizema parviflorum	DSF
Daviesia ulicifolia	WSF
Desmodium brachypodum	WSF
Dillwynia floribunda	WH
D. glaberrima	DHF,DH,WH
D. retorta ssp. *D*	DSF,DHF,DH,IDF
Glycine clandestina	WSF,DSF,DHF,DH,BT,HT
Gompholobium glabratum	DH
G. grandiflorum	DSF
G. latifolium	DSF,DHF
G. pinnatum	WH
G. virgatum ssp. *virgatum*	DSF,DHF,DH,IDF
Hardenbergia violacea	DSF,DHF,IDF
Hovea linearis	DSF,DHF,DH,IDF
H. longifolia	DSF
Indigofera australis	DSF
Kennedia prostrata	WSF,HT,VT,SG
K. rubicunda	WH,SF,S,BT,HT,FC,VT,DSF
Mirbelia rubiifolia	DHF,DH
Oxylobium ilicifolium	WSF
Phyllota phylicoides	DHF,DH,IDF
Platylobium formosum	DSF,HT,SG
Pultenaea blakelyi	DSF
P. daphnoides	VT,SG
P.microphylla var. *microphylla*	WHF
P. paludosa	WH
P. retusa	WHF
P. villosa	WSF
Sphaerolobium vimineum	WH
Viminaria juncea	DHF,WH,WHF,SF,S

GENTIANACEAE	
Centaurium tenuiflorum	WSF
GERANIACEAE	
Geranium homeanum	WSF,HT
G. solanderi	DSF
Pelargonium australe	BT,HT,FC
GOODENIACEAE	
Dampiera stricta	DHF,DH,WH,WHF
D. undescribed sp.	DSF
Goodenia hederacea	WSF,DSF
G. heterophylla	WSF,DSF,DHF
G. paniculata	WH,SF,S,FF
G. stelligera	WH
Scaevola calendulacea	HT,FC
HALORAGACEAE	
Gonocarpus micranthus	WH,SF,S,FF,BT,WHF
G. teucrioides	DSF,DHF,IDF,SG,BT
Myriophyllum aquaticum	sa
M. propinquum	SF,FF
HYPERICACEAE	
Hypericum japonicum	WSF,DSF,DHF
LAMIACEAE (LABIATAE)	
Plectranthus parviflorus	WSF,FC
Westringia fruticosa	HT
LAURACEAE	
Cassytha glabella	DHF,DH,WHF
C. pubescens	WH,SF
Endiandra sieberi	DSF,VT
Neolitsea dealbata	VT
LENTIBULARIACEAE	
Utricularia dichotoma	WH,S
U. exoleta	SF
U. uliginosa	SF
LINACEAE	
Linum trigynum	WSF
LOBELIACEAE	
Lobelia alata	SF,S,FF,VT
Pratia pedunculata	SG
P. purpurascens	WSF
LOGANIACEAE	
Mitrasacme paludosa	WH
M. polymorpha	DHF,DH
MALVACEAE	
Hibiscus diversifolius	BT
H. heterophyllus	WSF
*H. mutabilis**	BT
*Sida rhombifolia**	WSF
MELIACEAE	
Synoum glandulosum	HT,BT,VT
MENISPERMACEAE	
Sarcopetalum harveyanum	BT,HT,FC
Stephania japonica var. *discolor*	BT,HT,FC,VT,SG
MENYANTHACEAE	
Villarsia exaltata	SF,S,LS
MIMOSACEAE	
Acacia baueri spp. *baueri*	DHF,DH
A. binervata	WSF
A. elongata	WH,S,WHF,SF

A. floribunda	DSF,DH,WH
A. genistifolia	DHF,DH
A. implexa	WSF,SF
A. longifolia var. *longifolia*	DHF,IDF,BT,VT,HT
A. longifolia var. *sophorae*	FC,HT,BT
A. maidenii	DSF
A. myrtifolia	WSF
A. parramattensis	WSF,VT
A. suaveolens	DSF,DHF,DH,IDF,WH
A. trinervata	SF
A. terminalis	DSF,DH,IDF,WH
A. ulicifolia	DSF,DHF.DH,IDF
MORACEAE	
Ficus rubiginosa	WSF
Maclura cochinchinensis	DSF
MYRSINACEAE	
Rapanea variabilis	BT,DSF
MYRTACEAE	
Acmena smithii	VT,SG,HT,BT
Angophora costata AAADA	DSF,DHF,IDF,WHF,BT,DH
A. floribunda AAABB	WSF
A. subvelutina AAABA	WSF
Backhousia myrtifolia	VT,SG
Baeckea brevifolia	WH
B. imbricata	DH
Callistemon citrinus	SF,S
C. rigidus	SF,S
Calytrix tetragona	DSF,DH,IDF,DHF
Darwinia leptantha	DH,WH
Eucalyptus acmenoides MAG:C	WSF,DHF,DH
E. canaliculata SECEDC	WSF
E. grandis SECAB	WSF
E. gummifera CAFUF	DSF,DHF,DH,IDF
E. maculata CCC:B	WSF
E. microcorys SWA:A	WSF,DSF
E. paniculata SUV:D	WSF
E. pilularis MAIAA	WSF,DSF,DHF,IDF,DH
E. piperita ssp. *piperita* MATHAA	WSF
E. propinqua SECEA	WSF
E. resinifera SECCC	WSF
E. robusta SECAF	SF,WHF
E. signata MATKD	DHF
E. tereticornis SNEEB	WSF
Kunzea capitata	DHF,DH,IDF,WHF
Leptospermum attenuatum	DHF,DH,IDF
L. flavescens	DHF,DH,WH,WHF,SF
L. juniperinum	WH,SF,S
L. laevigatum	BT,HT,SG
L. liversidgei	WH,S
Lophostemon confertus (R.Br.) Peter G. Wilson & J. T. Waterhouse	WSF
Melaleuca armillaris	HT
M. nodosa	DHF,DH,WH,WHF
M. quinquenervia	DHF,WHF,SF,S,FF
M. sieberi	WH,WHF
M. styphelioides	WSF
M. thymifolia	DHF,DH,WH
Rhodomyrtus psidioides	DSF,VT
Syncarpia glomulifera	WSF
Syzygium oleosum (F. Muell.) Hyland	WSF
NYMPHAEACEAE	
*Nymphaea capensis**	sa,S
OLACACEAE	
Olax stricta	DHF,DH

OLEACEAE	
Notelaea longifolia	WSF,DSF
N. ovata	SG
ONAGRACEAE	
Ludwigia peploides ssp. *montevidensis*	FF
OXALIDACEAE	
Oxalis corniculata s. lat.	WSF,FC,SG
PASSIFLORACEAE	
*Passiflora subpeltata**	WSF
PEPEROMIACEAE	
Peperomia leptostachya	SF
PITTOSPORACEAE	
Billiardiera scandens	DSF,DHF,DH,IDF,BT,FC
Pittosporum undulatum	WSF,DSF,VT,BT
PLANTAGINACEAE	
Plantago debilis	HT
*P. lanceolata**	WSF,DSF
POLYGALACEAE	
Comesperma defoliatum	WH
C. retusum	DHF,DH
C. volubile	DH
POLYGONACEAE	
Polygonum strigosum	FF
Rumex acetosella L.*	WSF
PRIMULACEAE	
*Anagallis arvensis**	WSF,FF
Samolus repens	S,FF,HT
PROTEACEAE	
Banksia aemula R.Br.	DHF,DH,IDF,WHF
B. integrifolia	DSF,DHF,BT,HT,FC,VT,SG
B. oblongifolia Cav.	DHF,WH,WHF
B. robur	WH,WHF,S
B. serrata	DSF,IDF,BT
B. spinulosa	WHF
Conospermum taxifolium	DHF,DH,IDF
Hakea teretifolia	WH
Isopogon anemonifolius	DH,WH
Lomatia silaifolia	WSF
Persoonia hirsuta	DH,IDF
P. lanceolata	DH,IDF,WH,WHF
P. laurina	DSF,IDF,WHF
P. levis	WSF,DSF,IDF,WHF
P. linearis	WSF,VT
Petrophile sessilis	DSF,DHF,DH
Symphionema paludosum	WH
Xylomelum pyriforme	DSF
RANUNCULACEAE	
Clematis aristata	WSF,FF,VT
Ranunculus lappaceus	WSF
R. inundatus	FF
RHAMNACEAE	
Alphitonia excelsa	VT
Pomaderris ferruginea	WSF,SG
ROSACEAE	
Rubus parvifolius	WSF,HT
RUBIACEAE	
Opercularia varia	DSF,DHF,DH,BT,HT
Pomax umbellata	DSF,DHF,IDF,WHF,BT,HT,FC

RUTACEAE	
Acronychia wilcoxiana	DSF,BT,VT
Boronia falcifolia	DHF,DH,WH
B. parviflora	WH
B. pinnata	DSF,DHF,DH,IDF
Correa alba	BT,HT,FC,SG
C. reflexa	DSF,DHF,IDF,SG,BT
Eriostemon australasius	DSF,DHF,DH,IDF
Phebalium squameum	VT,DH
Zieria laevigata	DHF,DH
SANTALACEAE	
Exocarpos cupressiformis	WSF,DSF
E. strictus	DHF,WHF
Leptomeria acida	DSF,DHF
SAPINDACEAE	
Cupaniopsis anacardioides	WSF,DSF,FF,BT,HT,VT,SG
Dodonaea triquetra	WSF,DSF,VT,BT
SCROPHULARIACEAE	
Bacopa monnieri	DH
Euphrasia collina	DHF,DH
Gratiola pubescens	FF
SOLANACEAE	
Duboisia myoporoides	BT
Solanum campanulatum	WSF
S. cinereum	BT
S. nodiflorum ssp. *nutans*	WSF
S. pungetium	WSF
S. stelligerum	WSF
STACKHOUSIACEAE	
Stackhousia nuda	DH
S. spathulata	FC
S. viminea	DHF,DH
STERCULIACEAE	
Commersonia fraseri	VT,SG
Lasiopetalum ferrugineum	BT
STYLIDIACEAE	
Stylidium debile	SF,S
S. graminifolium	DHF,DH,IDF,WHF
S. lineare	WH
THYMELAEACEAE	
Pimelea linifolia	DSF,DHF,DH,IDF,BT,HT
Wikstroemia indica	HT,FC
TREMANDRACEAE	
Tetratheca ericifolia	DHF,DH,IDF
T. thymifolia	DSF,IDF,BT
ULMACEAE	
Trema aspera	HT,VT
VERBENACEAE	
Clerodendrum tomentosum	BT
*Lantana camara**	WSF
Verbena officinalis	WSF,HT
*V. rigida**	WSF
VIOLACEAE	
Viola hederacea	WSF,SF,BT,HT
V. sieberiana	SG
VITACEAE	
Cayratia clematidea	WSF,VT
Cissus antarctica	WSF,HT
C. hypoglauca	VT,SG
WINTERACEAE	
Tasmannia insipida	VT

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ABSTRACT

Benson, D. H. (National Herbarium of New South Wales, Royal Botanic Gardens, Sydney, New South Wales, Australia 2000) 1986. The vegetation of the Gosford and Lake Macquarie 1:100 000 vegetation map sheet. Cunninghamia 1(4):467–489. The composition and extent of the present natural vegetation on the Gosford and Lake Macquarie 1:100 000 map sheet (lat. 33° 00′–33° 30′S, long. 151° 00′–151° 45′E) is described and mapped in terms of structure, characteristic species and associated environmental factors. The area encompasses examples of almost all the structural and floristic vegetation types to be encountered in any area of coastal New South Wales. Twelve (12) map units are recognized, including estuarine communities, heaths, woodlands, open-forests and rainforests. The lack of adequate conservation reserves for some of the communities is discussed.

INTRODUCTION

The Gosford and Lake Macquarie Vegetation Map Sheet is the first in the Sydney Region Vegetation Map Series, a series of vegetation maps being prepared by the Ecology Section of the Royal Botanic Gardens, Sydney. The Series consists of vegetation maps at a scale of 1:100 000, corresponding to the Division of Natural Mapping 1:100 000 topographic sheets. The first sheets to be produced will be those within the Sydney 1:250 000 map area: Gosford and Lake Macquarie, Sydney, Penrith, St Albans, Wallerawang and Katoomba. These will be followed by the Wollongong map area, and ultimately the Newcastle and Singleton 1:250 000 map areas. Draft dyeline maps and explanatory notes are generally available for comment several years prior to publication.

METHODS

Areas of vegetation with similar structural and floristic characteristics were grouped on the basis of aerial photo-pattern, geology and landform to form the map units. Black and white aerial photography from the New South Wales Department of Lands (Gosford and Lake Macquarie 1:60 500 scale, flown in August 1980) was used. Only present-day natural vegetation is mapped. Field work involved checking of particular areas and recording notes on structure, characteristic species of major strata and associated environmental factors. Extensive species lists have not been presented though such data are being gradually compiled by the National Herbarium and are available either through Pickard (1972) and Bryant & Benson (1981) or on request.

The vegetation has been classified into the structural forms of Specht (1970). The structural forms (Table 1) are further subdivided by the dominant or characteristic species. An alpha-numeric code is used to identify map units. The numeric code represents the predominant structural form of the plant community (from Table 1) and the alphabetic code represents the characteristic species. Missing numbers are units that do not occur on this sheet area. This system has been used in Queensland for the Moreton Region Vegetation Map Series (McDonald & Whiteman, 1979).

The map units recognized are not all of equivalent rank. This is because some are essentially land-units made up of several plant communities associated with a particular geological or physiographic type (for example, map units 4a, 10a) whereas others are more clearly plant associations (*sensu* Beadle & Costin, 1952; for example, map units 9k, 12b).

TABLE 1

Structural classification of the vegetation based on Specht (1970)*

Life form and height of predominant stratum	Projective foliage cover of predominant stratum			
	70–100%	30–70%	10–30%	< 10%
Trees 30 m+	5. Tall closed-forests	6. Tall open-forests	7. Tall Woodlands	..
Trees 10–30 m ...	8. Closed-forests	9. Open-forests	10. Woodlands	11. Open-woodlands
Trees 6–10 m	12. Low closed-forests	13. Low open-forests	14. Low Woodlands	15. Low open-woodlands
Shrubs 2–8 m	16. Closed-scrubs	17. Open-scrubs	18. Tall shrublands	19. Tall open-shrublands
Shrubs 1–2 m	20. Closed-heaths	21. Open-heaths	22. Low shrublands	23. Low open-shrublands
Hummock grasses	..	..	24. Hummock grassland	25. Open hummock grassland
Herbaceous plants	26. Closed-herbland	27. Herbland	28. Open-herbland	29. Sparse-herbland

* Table from McDonald and Whiteman (1979).

Other units on map:

4. Littoral vegetation.

C. Disturbed areas—partly or wholly cleared for agriculture, forestry or urban use.

The vegetation map is a diagrammatic attempt to simplify the distributional patterns of an often rich and varied flora, over an extensive region. It is scale-dependent and map units will almost invariably include unmapped areas of other map units too small to be shown separately. Similarly, most plant communities do not have clear-cut boundaries but grade into each other, often over a broad ecotone. For mapping purposes such boundaries have to be approximated to a line.

Botanical names used are those currently recognized at the National Herbarium of New South Wales. Recent nomenclatural changes since the latest edition of Beadle, Evans & Carolin (1982), the relevant Flora, include a revision of *Tristania* (Wilson & Waterhouse, 1982) and the separation of *Allocasuarina* from *Casuarina* (Johnson, 1982).

GENERAL DESCRIPTION OF AREA

The Gosford and Lake Macquarie 1:100 000 Vegetation Sheet (based on the Gosford 1:100 000 Topographic Sheet 9131 and Lake Macquarie 1:100 000 Topographic Sheet 9231, Division of National Mapping, Canberra) is bounded by latitudes 33°00′ and 33°30′S and longitudes 151°00′ and 151°45′E. This area extends from Redhead, just south of Newcastle, southward along the coast to Terrigal near Gosford, and westward almost to Wollombi and Wisemans Ferry. The major coastal lake systems of Lake Macquarie and Tuggerah Lake are included, together with the urban centres of Gosford and Wyong. Much of the western half of the sheet is State Forest or National Park.

Climate

The area lies on the Subtropical East Coast (Gentilli, 1972) and experiences a generally mild climate. Average maximum temperatures for January, the hottest month, are about 28° C whilst average minimum temperatures for July, the coldest, range from 8° C on the coast to 3° C on the western edge (Bureau of Meteorology, 1979). Rainfall is highest in the Watagan Mountains in the north central part of the map sheet (average annual rainfall for Olney State Forest, lat. 33° 06′S, long. 151° 15′E, altitude 152 m, is 1614 mm). Average annual rainfall decreases to about 1000 mm on the western edge of the area and to about 1000 mm over Lake Macquarie. There is a slight increase along the coast. Gosford, on the southern edge of the sheet area, has an average annual rainfall of 1282 mm. March is generally the wettest month and October the driest. Summer winds are predominantly south to southeasterly with a tendency for onshore afternoon northeasterlies on the coast. Winter winds are predominantly west to southwesterly (Bureau of Meteorology, 1979).

Geology and Geomorphology

The sheet area lies at the northeastern corner of the Hornsby Plateau, which is a subdivision of the Sydney Basin, the large structural basin extending from Muswellbrook to Batemans Bay (Bembrick *et al.*, 1980). Several major north/south geological folds give rise to a series of major north/south ridge systems. One of these, the Hunter Range, divides the catchment of the Hawkesbury River, here essentially that of Mangrove Creek, from those of the other coastal creeks, Dora and Wyong Creeks. West of the Hunter Range is an extensive and deeply dissected plateau of Triassic Hawkesbury Sandstone which continues further westward as far as the Blue Mountains. In this area the plateau surface ranges between 200 and 300 m high. Softer sandstones and shales of the underlying Triassic Narrabeen Group are exposed in the gullies and narrow valleys cut through the Hawkesbury Sandstone. East of the Hunter Range most of the Hawkesbury Sandstone capping has disappeared, except for residuals on the Watagan Mountains (up to 400 m high), and steep, hilly country is formed from the Narrabeen Group sediments, here subdivided into the Gosford Formation Sandstone and the underlying Clifton Sub-group sandstone, claystones and shales (Figure 1). On the northeast corner are the Newcastle Coal Measures of Permian age, comprising shale, sandstone, conglomerate, tuff, chert and coal seams. In the Swansea–Redhead region these are covered with Quaternary sand. River and creek valleys contain deep deposits of Quaternary alluvium, and the coastal lakes are formed behind Quaternary barrier systems. Creeks entering these lakes (e.g., Dora Creek) have often built up characteristic 'silt jetties'. Around Woy Woy and Wyong–Tuggerah are extensive floodplains. Mount Warrawolong, a prominent dome-shaped hill of Tertiary-aged basalt, is the highest point of the area (640 m elevation). About a dozen small volcanic necks or diatremes also occur.

The Triassic sediments weather to grey and yellow-brown uniform sands on, or adjacent to, areas of strong relief, and sandy yellow leached gradational soils, often with ironstone gravels, on areas of gentle to moderate relief, particularly around Somersby (Hamilton, 1976). On steep slopes the high rate of erosion leaves a shallow soil that may contain fragments of parent material. On ridges and upper slopes in the Watagan Mountains are loose brown to dark grey sands and sandy loams. Fertility on these soils is low (Soil Conservation Service of New South Wales, in prep.). The Narrabeen Group sediments weather to loams and clays of moderate to high fertility. Floodplains and valley flats may have deep earthy yellow and brown alluvial sands and loams of low to moderate fertility. The fine-textured soils formed from the Clifton Sub-group have a high potential for deep gully erosion. The alluvial deposits are derived from the sandy material of the higher slopes and are prone to erosion once the vegetation cover has been removed. Erosion is increased by frequent fire.

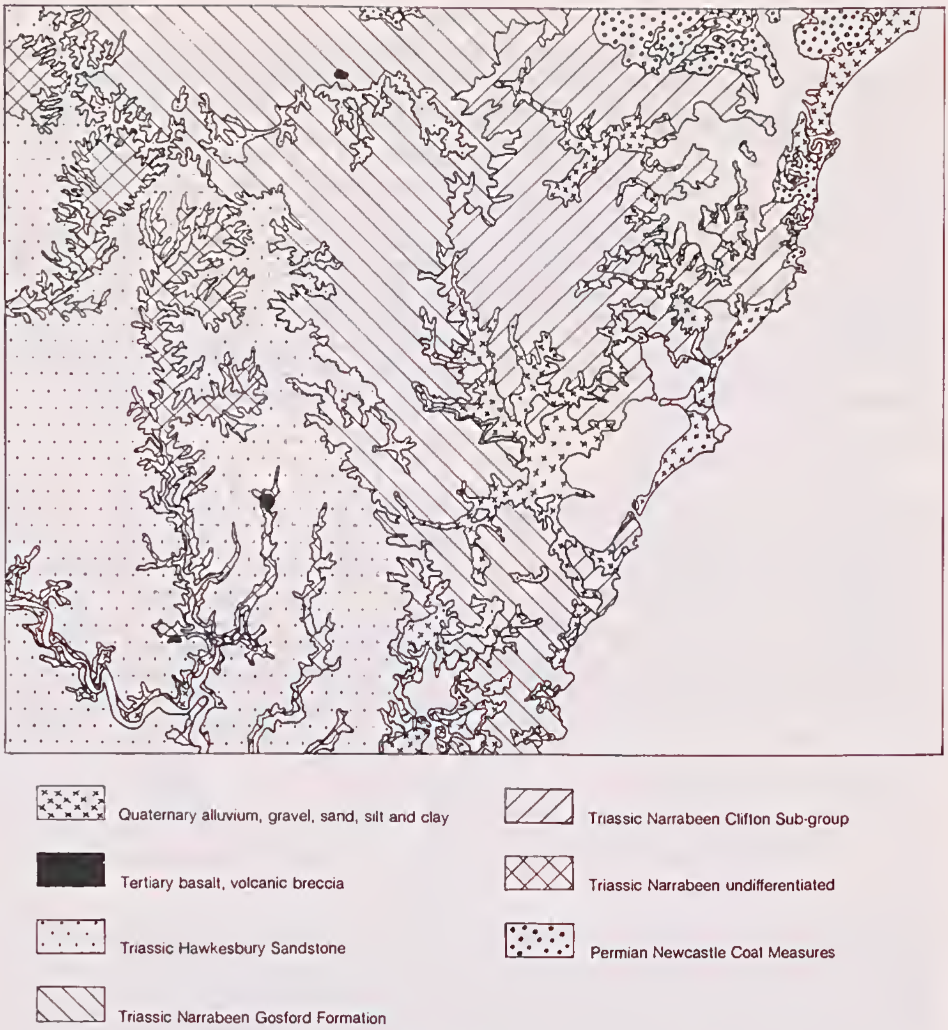
Quaternary alluvium, gravel, sand, silt and clay
Tertiary basalt, volcanic breccia
Triassic Hawkesbury Sandstone
Triassic Narrabeen Gosford Formation
Triassic Narrabeen Clifton Sub-group
Triassic Narrabeen undifferentiated
Permian Newcastle Coal Measures

Figure 1. Geological map of the Gosford–Lake Macquarie map sheet area (adapted from New South Wales Department of Mines, 1966).

Land-use

The Wyong district was first exploited by Europeans early last century as the cedar-cutters moved through. "The whole of this country, from Wyong to the Myall, and from Warrewolong to the Lakes, is very heavily timbered, particularly in the gullies; great quantities of cedar and other valuable woods abound, but are fast disappearing under the hands of the sawyers" wrote Raymond in 1832. As this timber was cut out settlers cleared land for farming. Wyong remained an important timber town well into the 20th century because of the large amount of hardwood timber in the mountains to the west, though, by 1916, with the first dedication of state forests, only the comparatively infertile and/or steep slopes remained forested.

Today, most of the more fertile soils particularly on the alluvial flats, has been cleared of native vegetation and replaced with improved pastures or citrus orchards. The resulting landscape is a mosaic of natural vegetation dissected by strips of agricultural or urban development. Important land-uses include citrus or stone fruit orchards, poultry, beef cattle, dairying, tomato and other cash crops (e.g., passionfruit) and plant nurseries. State forests cover large areas of uncleared rugged country in the centre and north of the map sheet. These include Ourimbah, Wyong, Watagan and Olney State Forests and are managed for the production of sawlogs and mining timbers.

The Gosford–Wyong region has been extensively developed for urban and associated recreational use, especially around Tuggerah Lake and Brisbane Water, and along the coast, particularly north of Swansea. Coal-mining occurs on the Newcastle Coal Measures and a number of major power stations are sited on the coastal lake margins.

The rugged country to the south of the map sheet, round the Hawkesbury River, is mainly National Park: Dharug, Brisbane Water and the recently gazetted Marramarra National Park in the far southwest. There are a number of small parks and reserves along the coast, including Munmorah State Recreation Area and Wyong Shire Council's North Entrance Nature Reserve.

VEGETATION

Apart from the specialized habitats such as mangroves and freshwater swamp, the vegetation of the map sheet belongs either to Beadle's (1981) eastern coastal lowlands tall *Eucalyptus* forests mostly on soils of higher fertility, or his *Eucalyptus* woodlands and forests on soils of low fertility. The vegetation of the Hawkesbury Sandstone of the Gosford region was included in Pidgeon's (1937, 1938, 1940, 1941) vegetation study of the Central Coastal area of New South Wales. Detailed descriptions of the vegetation of Brisbane Water National Park have been prepared by J. S. Benson & Fallding (1981) and for Mangrove Creek by D. H. Benson (1981). A vegetation survey of Dharug National Park is currently (1986) being undertaken at the Royal Botanic Gardens, Sydney. There are also a series of dyeline 1: 25 000 scale "Forest Type" maps covering Olney, Ourimbah, Watagan and Wyong State Forests available from the Forestry Commission of New South Wales. Further information is limited to species lists for local areas, references to which are given in the appropriate plant community descriptions.

A summary of the map units recognized here, their structural formations, main canopy species and geological substrates are given in Table 2. Species of particular conservation importance are listed in Table 3, major conservation areas in Table 4 (see p. 486). The vegetation map sheet is located inside the back cover.

Plant community descriptions

4a *Estuarine complex*

Estuarine vegetation is found on alluvial mudflats along the Hawkesbury River, its tributaries, Mangrove Creek and Mooney Mooney Creek, and in the bays of Brisbane Water, especially around The Rip, and Ripleys and Pelican Islands. Extensive clearing and reclamation for foreshore development has taken place around Gosford and Woy Woy. For example, St Huberts Island, at the entrance to Brisbane Water, has been completely cleared for canal-estate housing. In the Lake Macquarie and Tuggerah Lake areas estuarine vegetation is found at the head of Lake Eraring, around the shores of Muddy Lake, at the tips of the Dora Creek silt jetties, Whiteheads Lagoon and at the entrance to Lake Macquarie at Swansea.

Estuarine vegetation generally consists of zones of vegetation, often of different structural formations. The main factor in the explanation of plant distribution is the influence of tide and elevation on salinity in relation to the environmental requirements and tolerance ranges of the plant species. Plant zonation is closely associated with elevation above mean sea level, and very small differences in microtopography are involved (Clarke & Hannon, 1969).

TABLE 2

Map unit, structure, main canopy species, geology and occurrence of plant communities on the Gosford and Lake Macquarie 1:100 000 vegetation map sheet

Map unit	Structural formation	Main canopy species	Geology	Occurrence
4a	OPEN-SCRUB	*Avicennia marina*	Quaternary alluvium	Estuarine mudflats, regular tidal inundation
	HERBLAND	*Sarcocornia quinqueflora*		Occasional tidal inundation
	RUSHLAND	*Juncus kraussii*		Infrequent tidal inundation
	LOW OPEN-FOREST	*Casuarina glauca, Baumea juncea*		Poorly drained, some saline influence
6e	TALL OPEN-FOREST	*Eucalyptus saligna, Syncarpia glomulifera, Angophora costata, E. pellita*	Clifton Sub-group Gosford	Deep, sheltered gullies, southeast aspects
8a	CLOSED-FOREST	*Ceratopetalum apetalum, Doryphora sassafras, Acmena smithii, Livistona australis,* Emergents—*Eucalyptus deanei, Syncarpia glomulifera*	Narrabeen Group	Sheltered gullies, fertile soils
8b	CLOSED-FOREST	*Melaleuca linariifolia, M. styphelioides,* Emergents—*Eucalyptus robusta, E. longifolia*	Quaternary alluvium	Poorly-drained creek flats
	SCRUB	*Melaleuca ericifolia, M. sieberi, M. decora, M. nodosa, M. linariifolia, M. thymifolia*		Poorly-drained flats often on poor soils
9g	OPEN-FOREST	*Angophora costata, Eucalyptus gummifera, E. capitellata, E. pilularis.*	Narrabeen Group and Permian sandstones	Gentle slopes, ridge tops and valley floors
		E. maculata, E. umbra, E. siderophloia, E. punctata		Steeper slopes on ridge sides

Map unit	Structural formation	Main canopy species	Geology	Occurrence
9h	OPEN-FOREST	*Eucalyptus deanei, E. acmenoides, Angophora floribunda, Syncarpia glomulifera*	Narrabeen Group	Valleys, or lower valley slopes, sheltered aspects
		Angophora floribunda, E. punctata, E. tereticornis, E. eugenioides, Allocasuarina torulosa		Dry northern or western aspects
9k	OPEN-FOREST	*Angophora costata*	Quaternary sand dunes	Sheltered coastal dunes, North Entrance
10a	OPEN-FOREST/ WOODLAND	*Eucalyptus piperita, Angophora costata*	Hawkesbury Sandstone	Sheltered hillsides, gullies
	LOW WOODLAND	*E. gummifera, E. eximia, E. punctata, E. haemastoma*		Ridges, plateaux and dry exposed hillsides
	OPEN-SCRUB	*Banksia ericifolia, Hakea teretifolia*		Poorly-drained situations
		Angophora hispida, Lambertia formosa, Banksia serrata		Dry rocky ridges, shallow soil
	OPEN-HEATH	*Allocasuarina distyla, Baeckea spp., Darwinia spp.*		Patches in isolated depressions on rock platforms
	SEDGELAND	Cyperaceae and Restionaceae, *Banksia robur*		Swampy organic soils with impeded drainage
10e	WOODLAND	*Eucalyptus haemastoma*	Clifton Sub-group	Broad low ridges with poor soils
21a	OPEN-HEATH	*Melaleuca nodosa, Allocasuarina distyla, Lambertia formosa, Banksia oblongifolia, Hakea teretifolia*	Clifton Sub-group/ Permian coal measures	Shallow soils or exposed situations, generally coastal
	GRASSLAND	*Themeda australis*		Headlands
	SEDGELAND	*Melaleuca thymifolia, Leptospermum juniperinum, Callistemon citrinus*		Poorly-drained sites

Map unit	Structural formation	Main canopy species	Geology	Occurrence
21b	OPEN-HEATH	*Banksia aemula*	Quaternary aeolian sand (Pleistocene)	Coastal headlands
	CLOSED-SCRUB	*Leptospermum laevigatum, Banksia integrifolia, Acacia longifolia*	Aeolian sand (Recent)	Coastal dunes
	LOW CLOSED-FOREST	*Cupaniopsis anacardioides, Livistona australis*		Lee side of larger dunes
27a	SEDGELAND	*Eleocharis spp., Baumea spp., Juncus spp., Alisma plantago-aquatica, Philydrum lanuginosum*	Quaternary alluvium	Floodplains or behind dune systems where soils are periodically waterlogged
		Phragmites australis		Brackish water
	CLOSED-SCRUB	*Melaleuca ericifolia, Gahnia clarkei*		Shorter periods of inundation and waterlogging
	OPEN-FOREST	*Melaleuca quinquenervia, Casuarina glauca, Eucalyptus robusta, E. amplifolia*		
C	CLEARED	Native vegetation has been largely removed for agricultural or suburban development but remnant vegetation of varying size and condition may remain.		

The zonation is broadly as follows. On the outermost side of the mudflat is a zone of mangrove open-scrub, commonly 1 to 5 m high and dominated by *Avicennia marina.* The other mangrove species that may be found is *Aegiceras corniculatum,* a smaller, less abundant plant generally confined to the inner edges of the mangrove zone. The mangrove zone is subjected to a relatively high number of high tides (Clarke & Hannon, 1969). Behind the mangrove zone may be a zone of saltmarsh, a herbland dominated by succulent members of the Chenopodiaceae, *Sarcocornia quinqueflora* and *Suaeda australis.* These plants are less than 0.5 m high and are inundated by sea water only during very high tides or at flood periods. These areas are often waterlogged and have a high salinity. Behind this may be a zone of rushland with *Juncus kraussii* and *Sporobolus virginicus.* These areas receive infrequent inundation. Finally there is a zone of swamp forest with *Casuarina glauca* or *Eucalyptus robusta,* often with an understorey of *J. kraussii* or *Phragmites australis,* the latter indicating a brackish rather than saline environment. This zone is not directly flooded. Where sandstone hillsides abut the water's edge and there is no accumulated alluvium, the zonation may be reduced to a line of mangroves and a few trees of *C. glauca.*

The estuarine wetlands of Brisbane Water are significant within the context of the Sydney Region, with mangroves representing approximately 14 per cent and saltmarshes approximately 28 per cent of the Sydney Region resources.

Reasonably large areas of mangroves still survive—indeed the area of mangroves in Brisbane Water increased overall by 25 ha between 1954 and 1979, as a result of increased siltation resulting from clearing and disturbance in catchment areas. In contrast the area of saltmarsh has been substantially reduced (by 60 per cent since 1954) by reclamation (New South Wales Department of Environment and Planning, 1983). Important areas of saltmarsh include Cockle Bay, Rileys Island, lower Mangrove Creek and near Singletons Mill on the Hawkesbury (Benson, 1974). Rushland and *Casuarina glauca* are still fairly common, though *Eucalyptus robusta* communities are rare and inadequately conserved.

Detailed studies of similar mangrove and saltmarsh communities and the requirements of individual species have been carried out by Clarke & Hannon (1967, 1969, 1970, 1971) at Towra Point on the southern shore of Sydney's Botany Bay. Descriptions of estuarine communities within the area have been compiled for Brisbane Water National Park (J. S. Benson & Fallding, 1981), Lake Eraring (Waterhouse & Quinn, 1974), Kincumber (Thorvaldson, 1975) and Wyce Creek (Pickard, 1973).

6e *Tall open-forest: Eucalyptus saligna*

This community is associated with deep, sheltered gullies with south-easterly aspects on the Gosford Formation and the Clifton Sub-group. Such sites occur below the escarpments of the Watagan Mountains and other ridges in the catchment of Dora Creek. There are numerous small patches in the steep headwater sections of gullies though these are too small to be shown on the map sheet. The species present at any site vary according to micro-relief. Common large trees are *Eucalyptus saligna, Syncarpia glomulifera, E. pellita, Angophora costata* and *E. acmenoides.* Smaller trees include *E. umbra, Melaleuca styphelioides* and *Allocasuarina torulosa.* Shrubs include *Acacia binervata, A. irrorata* and *Rhodamnia rubescens,* and vines are common, including *Ripogonum fawcettianum, Pandorea pandorana, Eustrephus latifolius* and *Dioscorea transversa.* The ground cover is mainly ferns, *Blechnum cartilagineum* and *Pteridium esculentum* and graminoids, *Gahnia melanocarpa* and *Gymnostachys anceps.*

On slightly drier sites are *Eucalyptus maculata, E. siderophloia, E. umbra* subsp. *umbra, E. punctata, E. paniculata* and *Allocasuarina torulosa.* Here the understorey is dominated by grasses, mainly *Imperata cylindrica, Entolasia stricta* and *Poa affinis.* Other species include the small tree *Pittosporum revolutum* and the vine *Eustrephus latifolius.* Extensive logging has been carried out in most areas.

There were once extensive tall open-forests of *Eucalyptus saligna* on the alluvial flats of Wyong, Ourimbah and Jilliby Jilliby Creeks, though these have been cleared for agriculture.

8a *Closed-forest: rainforest*

Closed-forest dominated by rainforest species is found in deep, sheltered valleys on cool, southern to eastern aspects of varying geology but most commonly on the Narrabeen Group or on alluvium. An extensive occurrence is in Strickland State Forest near Somersby and smaller patches are common around Ourimbah. Rainforest species generally form a closed-forest canopy up to 12 m high though there may be emergent eucalypts up to 30 m high. The main rainforest species are *Ceratopetalum apetalum, Doryphora sassafras, Acmena smithii, Livistona australis* and occasionally *Archontophoenix cunninghamiana,* the palms being in poorly-drained sites. This canopy tends to be continuous with the tall shrub layer of species such as *Backhousia myrtifolia, Trochocarpa laurina, Tristaniopsis collina* and *T. laurina, Notelaea* spp., *Wilkiea huegeliana* and *Eupomatia laurina.* The ground cover is usually dominated by ferns such as *Blechnum cartilagineum, Culcita dubia, Asplenium* spp. and *Doodia aspera.* Other understorey species include the climbers *Smilax* and *Cissus,* orchids and other monocotyledons. Emergent tree species include *Eucalyptus deanei* and *Syncarpia glomulifera* (J. S. Benson & Fallding, 1981). There are also a number of planted specimens of *Araucaria cunninghamii* and *A. bidwillii* in Strickland State Forest.

Small pockets of rainforest are also found in sheltered gullies in the Watagan Mountains further north, associated with tall open-forest (community 6e) and open-forest (community 9g).

Remnant rainforest also survives as a gallery forest along the banks of creeks such as Ourimbah and Wyong Creeks, though often heavily infested with exotic weeds. It rarely extends more than 20 m from the creek edges, the surrounding country being generally cleared for grazing or agricultural land. Originally such sites carried large trees of *Toona australis* which were exploited by the cedar-cutters early last century. Common tree species now include *Livistona australis, Tristaniopsis laurina, Cryptocarya glaucescens, Lomatia myricoides, Backhousia myrtifolia, Ceratopetalum apetalum* and *Acmena smithii.* Vines and lianes include *Smilax australis, Morinda jasminoides, Malaisia scandens* and *Ripogonum album. Eucalyptus saligna* is a common emergent tree, this community frequently grading into tall open-forest (community 6e). Invasion by exotic weed species such as *Ligustrum sinense, Cinnamomum camphora* and *Tradescantia albiflora* is a major threat to the survival of rainforest remnants.

A number of rainforest species reach their southern distributional limit in the Gosford–Wyong region: *Elaeocarpus obovatus* (Elaeocarpaceae) *Dysoxylum fraseranum* (Meliaceae) and *Ripogonum fawcettianum* (Smilacaceae) and *Tetrastigma nitens* (Vitidaceae) (Williams, 1979).

8b *Melaleuca swamp forest*

This community occurs on poorly-drained alluvial swamp flats in small to medium-sized valleys of streams flowing into Lake Macquarie or Tuggerah Lake.

The main component of the community is a layer of small trees from 10 to 15 m high forming a closed canopy (90 per cent or more canopy cover). Stem density is very high. The characteristic species are *Melaleuca linariifolia, M. styphelioides* and occasionally *M. sieberi.* Frequently there are scattered emergent *Eucalyptus robusta* or *E. longifolia* trees up to 20 m tall. In some places the *Melaleuca* canopy is lower and forms a scrub or heath structure. Predominant species may be *Melaleuca ericifolia, M. sieberi, M. decora, M. nodosa, M. linariifolia* and occasionally *M. thymifolia.*

The groundcover in the closed-forest is variable, but generally includes *Entolasia* spp., *Imperata cylindrica, Viola hederacea, Pratia purpurascens, Glycine clandestina* and *Eustrephus latifolius.* Associated with the scrub may be sedges such as *Schoenus brevifolius* and herbs such as species of *Hydrocotyle* and *Gonocarpus,* and *Selaginella uliginosa.* Near watercourses are larger graminoids, *Gahnia clarkei, Baumea juncea* and *B. articulata.* Many of the *Melaleuca* swamps in the larger valleys have been cleared for agriculture, and burning and grazing, and trampling, often associated with paper-bark collection for the horticulture trade, frequently leads to understorey deterioration. However, there is only limited knowledge of the flora of these swamps and, because very few are in conservation areas, further study should be directed towards them.

9g *Open-forest: Eucalyptus gummifera–E. maculata–E. pilularis*

This community is very widespread on claystones, sandstones and shales of the Clifton Sub-group, the Gosford Formation and the Newcastle Coal Measures. Soils range from podzolized sands to deep sandy loams. Species composition is very variable and changes from the coastal lowlands to the higher country to the west.

The trees are about 20 m high and crowns are separate and readily distinguished. The canopy is more open on north-facing slopes than on those facing south. In coastal areas particularly on the Clifton Sub-group, there are two sub-communities that tend to form a mosaic. Characteristic species of the first group are *Eucalyptus gummifera, E. capitellata, Angophora costata* and *Allocasuarina littoralis* which are found on shallow slopes, such as on ridges and spurs, or in valleys. On wetter sites, *E. pilularis* occurs. Common shrubs are *Lambertia formosa, Leptospermum attenuatum, Epacris microphylla* and *Dillwynia retorta.* The ground cover is dominated by grasses such as *Imperata cylindrica, Entolasia stricta* and *Themeda australis.* On steeper slopes, where talus material is present and colluvial soil is mainly found trapped by boulders, the second sub-community occurs: *Eucalyptus maculata* is the most characteristic species, with other common species being *E. umbra* subsp. *umbra, E. siderophloia, E. punctata* and *Allocasuarina torulosa.* Common shrubs are *Daviesia ulicifolia, Bursaria longisepala, Oxylobium scandens* and the exotic weed *Lantana camara.* The ground cover is dominated by the grasses *Themeda australis, Imperata cylindrica* and *Entolasia stricta,* but also common is the grass *Poa affinis,* the herb *Pseuderanthemum variabile* and the vine *Eustrephus latifolius.*

On country of stronger relief further west are extensive state forests. Here, on soils on the Gosford Formation, *Eucalyptus pilularis* is a characteristic species, sometimes forming pure stands, but often associated with *E. paniculata, E. propinqua, E. umbra, E. agglomerata, E. acmenoides* or *Angophora floribunda.* On moister sites, species include *E. saligna, E. deanei* and *Syncarpia glomulifera.*

Understoreys are typically grassy and open in the drier places, commonly with much *Imperata cylindrica.* In more sheltered gully sites with deeper, more fertile soils the understorey is very tall and denser with "rainforest" trees and shrubs such as *Ceratopetalum apetalum, Callicoma serratifolia, Tristaniopsis collina* and *Acacia elata,* and vines such as *Cissus hypoglauca* and *C. antarctica.* In some places a fern stratum with *Culcita dubia* and *Blechnum cartilagineum* predominates.

An isolated stand of *Eucalyptus fastigata* is found on the slopes of Mt Warrawolong, a basalt-capped mountain. A number of major ridges east and south of Mt Warrawolong are shown on the geological map (New South Wales Department of Mines, 1966) as Hawkesbury Sandstone. There is some *Eucalyptus piperita,* a common sandstone species, but the characteristic sclerophyllous shrub understorey of the Hawkesbury Sandstone Complex (community 10a) is absent. Generally the vegetation has *Angophora floribunda* and *Syncarpia glomulifera* and is more similar to the varied eucalypt open-forest (community 9g).

These forests have been extensively logged in the past and are very much altered from their original pre-settlement structure, though floristically they may be essentially unaltered except where cleared or frequently burnt. Extensive areas have been cleared for plantations of *Eucalyptus pilularis* and *E. agglomerata.*

Species lists have beeen compiled for Pulbah Island Nature Reserve (Messmer, Bryce & Rupp, 1941), Eraring (Waterhouse & Quinn, 1974), Gwandalan and Charmhaven (New South Wales Department of Public Works, 1978), Kincumber (Thorvaldson, 1975), Wyee Creek (Pickard, 1973), Redhead district (McDonald *et al.,* 1971) and Newcastle district, south to Swansea (Morris, 1969).

9h *Open-forest: Eucalyptus deanei–Angophora floribunda*

This community is found on sediments of the Narrabeen Group that commonly outcrop in valleys or on lower hillsides below cliffs and ridges of Hawkesbury Sandstone, particularly in the valleys of the Hawkesbury River and its tributaries, Mangrove and Mooney Mooney Creeks. Slopes are steep and the soils are clayey. There are two recognizable subunits:

(i) The first occurs on more sheltered sites, closer to the coast, and is often associated with rainforest gullies (community 8a). The main tree species are *E. deanei, E. acmenoides, Angophora floribunda, Syncarpia glomulifera* and *Allocasuarina torulosa.* Common species in the tall shrub layer are *Acmena smithii, Backhousia myrtifolia, Acacia prominens* and *Ficus rubiginosa.* The ground cover is mainly of ferns such as *Doodia aspera* and *Culcita dubia,* graminoids such as *Imperata cylindrica* and *Themeda australis,* and *Lomandra* spp., herbs and climbers.

(ii) The second subunit occurs on drier, often westerly facing sites. Around Brisbane Water National Park, for example, common tree species are *Angophora floribunda* and *Allocasuarina torulosa* with other species including *E. paniculata, E. punctata, E. resinifera* and *Callitris muelleri.* Further west, species such as *E. tereticornis* and *E. eugenioides* become common. The diverse shrub layer contains species such as *Dodonaea triquetra, Oxylobium ilicifolium, Persoonia* spp. and *Jacksonia scoparia.* The ground cover is mainly grasses and herbs. This community grades into the varied eucalypt open-forest community 9g. Published descriptions are available for upper Mangrove Creek (D. H. Benson, 1981) and Brisbane Water National Park (J. S. Benson & Fallding, 1981).

9k *Open-forest: Angophora costata*

Open-forest of *Angophora costata* is found on the North Entrance Peninsula on a series of Quaternary sand ridges and swales, the largest undisturbed area of coastal sand-dunes between Sydney and Newcastle. The vegetation on the eastern side of the Peninsula and on similar sand dunes further north has been destroyed by mineral-sand mining but an area known as the "Red Gum Forest" has been saved by Wyong Shire Council and is now managed as a Nature Reserve. Here then are trees of *Angophora costata* (locally called Red Gum), 10 to 15 m high often with smaller trees of *Banksia serrata.* Occasional trees of *Allocasuarina torulosa, Eucalyptus botryoides* and *E. gummifera* may be found (Figure 2). There is a dense shrub layer from 0.75 to 2 m in height. The ground is typically covered with leaf litter; low herbs and grasses are uncommon. *Dillwynia glaberrima* is the most common shrub species in many areas. In some places *Macrozamia communis* predominates but in others there may be a variety of shrub species including *Ricinocarpos pinifolius, Leucopogon ericoides* and *Pimelea linifolia.* Timms (1975) gives a description of this vegetation together with an analysis of flowering times. Small patches of littoral rainforest (of low closed-forest structure) are associated with sheltered swales at the southern end of the North Entrance open-forest. Rainforest species include *Cupaniopsis anacardioides, Livistona australis, Acmena smithii* and *Alphitonia excelsa.* Small, often degraded littoral rainforest patches may also be found further north.

10a *Open-forest/Low Woodland/Open-scrub (Hawkesbury Sandstone Complex)*

This is the widespread vegetation complex found on the Hawkesbury Sandstone areas of the map sheet. It contains considerable local structural and floristic variation depending particularly on topographic position, drainage and aspect. Various sub-units and topographic sequences can be recognized but because of the large area involved, and the scale of mapping, it has been

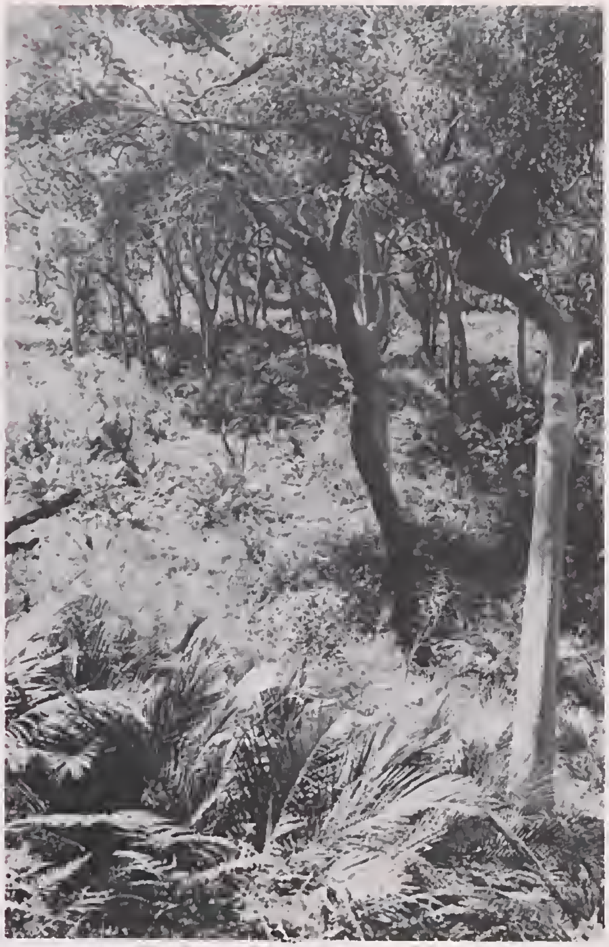

Figure 2. *Angophora costata* with understorey of sclerophyllous shrubs including *Macrozamia communis* (community 9k).

practical to map only a very broad unit. An idea of the variation to be expected within this unit can be obtained from the larger scale (1:50 000) vegetation map of J. S. Benson & Fallding (1981) who have mapped seven plant communities for the Hawkesbury Sandstone of the northern half of the Brisbane Water National Park.

Structurally, the vegetation ranges from open-forest to woodland and low woodland, and to open-scrub and sedgeland. In sheltered sites, with southerly or easterly aspects, on hillsides or in shallow valleys, is open-forest dominated by *Eucalyptus piperita* subsp. *piperita* and *Angophora costata.* Other tree species vary with situation, and include *E. oblonga, E. umbra* subsp. *umbra, E. gummifera* and *E. haemastoma* near Brisbane Water National Park, and *Syncarpia glomulifera, Allocasuarina torulosa* and *Acacia elata* near Mangrove Creek. The understorey is very diverse, a mixture of sclerophyllous shrubs forming a layer up to 1 m high, and a ground cover of *Pteridium esculentum* and graminoids including sclerophyllous grasses and sedges. *Doryanthes excelsa* may be locally abundant.

Similar vegetation is found on the Hunter Plateau, on deep, sandy, yellow, leached, gradational soils from Kariong through Peats Ridge towards Bucketty. The vegetation on these sites is normally an open-forest to low open-forest with

Angophora costata, Eucalyptus haemastoma and *E. sieberi* and a large number of proteaceous shrubs, such as *Petrophile pulchella, Hakea* spp., *Lambertia formosa, Banksia spinulosa, Persoonia* spp., *Telopea speciosissima, Xylomelum pyriforme* and *Grevillea* spp. *Doryanthes excelsa* may be conspicuous. Mixed with these species are those of nearby communities, including *Syncarpia glomulifera, E. gummifera, E. punctata, E. oblonga, E. capitellata* and *Banksia serrata.* Shrubs include *Leptospermum* spp., *Acacia* spp., *Bossiaea* spp. and *Gompholobium* spp. and the ground species such as *Actinotus minor, Dampiera stricta* and *Gonocarpus teucrioides.* Because they tend to be deeper and more amenable to agriculture than most of the sandstone-derived soils, the yellow-earth soils here have been actively sought and cleared, particularly in recent years.

Low woodland or low open-woodland occurs on drier ridgetops and spurs, with shallow skeletal soils. The main trees are *Angophora costata, E. gummifera, E. eximia, E. umbra* subsp. *umbra, E. haemastoma* and *E. punctata. Eucalyptus racemosa* and *Angophora bakeri* are common on the western side of the area. Shrubs are common in the very diverse understorey. Common families (and genera) are Proteaceae (*Banksia* spp., *Hakea* spp.), Fabaceae (*Pultenaea* spp., *Dillwynia* spp.), Epacridaceae (*Epacris* spp., *Leucopogon* spp.), Rutaceae (*Boronia* spp., *Eriostemon australasius*), Myrtaceae (*Leptospermum* spp., *Angophora hispida*) and *Acacia* spp. The ground cover is mainly sclerophyllous monocotyledons, such as *Entolasia stricta, Lepidosperma* spp., *Lepyrodia scariosa, Lomandra* spp., *Schoenus* spp. and *Xanthorrhoea media.*

On ridgetops, valley heads and drainage lines where drainage is locally impeded, closed-scrub or open-scrub is found. There are occasional scattered trees, such as *E. haemastoma, E. umbra* and *E. gummifera,* but the main structural feature is the shrub layer. This is 2 to 5 m high and composed of densely packed large shrubs in wetter situations, but is more open in drier places. The most common species are *Banksia ericifolia* and *Hakea teretifolia.* Interspersed are species of *Grevillea* and *Leptospermum.* The ground cover is mainly sclerophyllous monocotyledons, such as *Restio* spp., *Lepyrodia scariosa, Xanthorrhoea resinosa* and *Lomandra* spp.

At the northern end of the Judge Dowling Range, south of Bucketty, is a broad, relatively undissected ridge with distinctive patches of open-scrub vegetation. These contrast with the typical low open-woodland of the surrounding ridges. The soil is very shallow and skeletal, with patches of sand. Common shrub species include *Banksia serrata, B. ericifolia, Lambertia formosa, Angophora hispida* and *Persoonia lanceolata.* Two scribbly gum species, *Eucalyptus haemastoma* and *E. racemosa,* grow together though *E. haemastoma* is generally absent from the adjacent ridges particularly to the west and south.

In depressions on sandstone rock shelves there may be pockets of heath interspersed with scattered small trees, mainly *Eucalyptus haemastoma* and *E. eximia.* Shrubs species include *Allocasuarina distyla, Baeckea* spp., *Darwinia fascicularis, Eriostemon australasius, Kunzea* spp., *Leptospermum* spp., *Angophora hispida* and various epacridaceous species. Graminoids are common, especially on the shallower soils on the peripheries of the pockets. Species found here include *Caustis pentandra, Lepidosperma* spp. and *Restio* spp.

On swampy organic soils, particularly in the area covered by the southern half of the map sheet where rainfall is higher, are patches of sedgeland. These are usually on plateaux or in shallow basins where impervious shale layers direct the water-table to the surface. The dominant vegetation cover is a layer of graminoids, including *Restio* spp., *Chorizandra* spp., *Cyathochaeta diandra, Gymnoschoenus sphaerocephalus, Lepidosperma* spp. and *Leptocarpus tenax.* Associated shrub species include *Banksia robur, Sprengelia incarnata* and *Leptospermum juniperinum.* Scattered shrubs of *Banksia oblongifolia* and *Hakea teretifolia* are frequent on drier sandy soils. Throughout are herbs such as

Drosera spp., *Dampiera stricta, Goodenia bellidifolia* and *Selaginella uliginosa.* Creeks are commonly fringed with *Tristaniopsis laurina, Leptospermum flavescens* and *Callicoma serratifolia.*

The greatest diversity in the Hawkesbury Sandstone complex is found in the southeast of the area especially within Brisbane Water National Park (J. S. Benson & Fallding, 1981). Here, there appears to be a high frequency in the number of outcropping shale bands within the sandstone. This, together with a high rainfall, results in numerous localized soaks and extensive variation in soil water distribution, leading to mosiacs of scrub, heath and sedgeland. To the northwest the diversity decreases, especially in the shrub-layer. West of Mangrove Creek only open-forest and low open-woodland are common, with heath infrequent (Benson, 1981).

The Hawkesbury Sandstone Complex is included within the Mixed *Eucalyptus* Forest Association of Pidgeon (1937, 1938, 1940, 1941), and the *Eucalyptus gummifera–E. racemosa–E. sieberi* Alliance of Beadle (1981). Floristic lists for Dharug National Park are given by the Linnean Society (1971) and Matthew (1973).

10e *Woodland: Eucalyptus haemastoma*

This community is restricted to the tops of low broad ridges with a northerly aspect to easterly aspect on poor sandy soils derived from the Clifton Sub-group of the Narrabeen Group. Occurrences range from Wyong northwards on both sides of Lake Macquarie. The structure of the community varies from open-forest to very scattered woodland. Tree height is less than 20 m and species are *Eucalyptus haemastoma* or less commonly *E. racemosa.* A dense shrub layer, about 0.5 m high overlies a variable, but usually open, ground cover. Shrub species include *Leucopogon microphyllus, Leptospermum attenuatum, Epacris microphylla* and *Banksia oblongifolia.* The ground cover is dominated by sedges and sclerophyllous graminoids. The main species are *Ptilanthelium deustum, Xanthorrhoea macronema* and *Entolasia stricta.*

21a *Open-heath/Grassland/Sedgeland*

This is coastal vegetation which is low, scrubby and treeless, both because of the low nutrient status of its soils and because it is exposed to onshore winds that restrict tree growth. It is found on soils developed from Narrabeen and Permian claystone, sandstone and shales and Quaternary alluvium from Lake Munmorah to Redhead. Height ranges from open-heath 1–2 m high, down to grassland 30 cm high. Soils are generally clayey or sandy, and exposure ranges from reasonably sheltered to very exposed. Common shrubs in the open-heath include *Melaleuca nodosa, Allocasuarina distyla, Lambertia formosa, Banksia oblongifolia, Hakea teretifolia* with clumps of mallee *Eucalyptus capitellata* or *E. umbra.* On exposed headlands, particularly around Catherine Hill Bay are extensive grasslands of *Themeda australis.* Local species composition depends on soil depth and drainage. In poorly-drained sites particularly in broad valleys, sedgeland develops. Species here include the graminoids, *Lepyrodia scariosa, Leptocarpus tenax* and *Schoenus brevifolius* and the shrubs *Melaleuca thymifolia, Leptospermum juniperinum, Callistemon citrinus* and *Viminaria juncea* as well as sedges and grasses.

Coastal vegetation has been described at Fraser Park (now Munmorah State Recreation Area) (New South Wales Department of Public Works, 1978) and Redhead (McDonald *et al.*, 1970, 1971).

21b *Open-heath: Banksia aemula*

This community is found on coastal headlands on deposits of highly leached white sand of Pleistocene age (P. Myerscough pers. comm.) that overlie the Triassic and Permian sediments. It forms a closed to open-heath

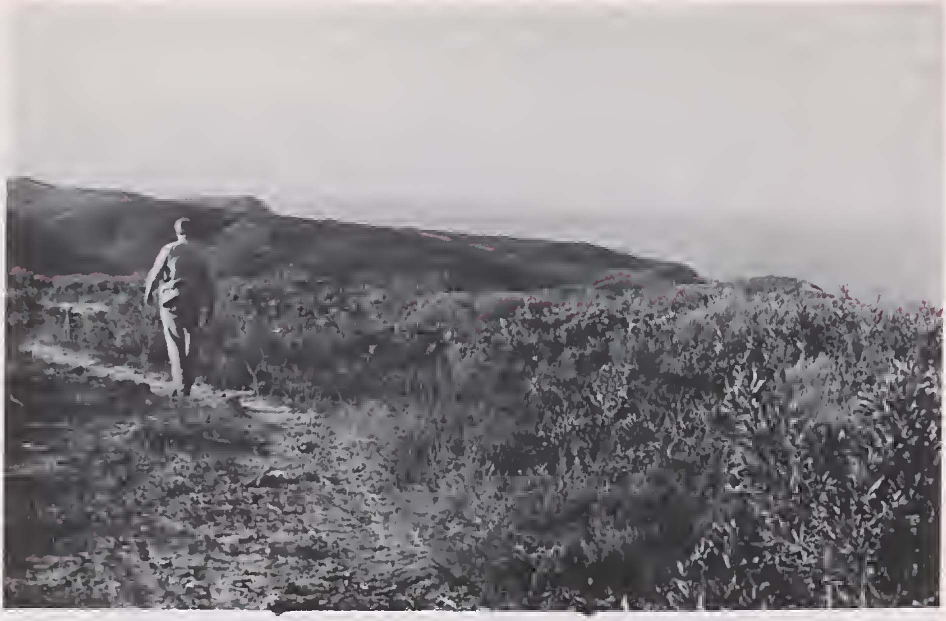

Figure 3. Open-heath with *Banksia aemula* on Pleistocene sand deposits on Wybung Head near Swansea (community 21b).

characterized by the shrub *Banksia aemula* (formerly *B. serratifolia*) (Figure 3). Common smaller shrubs include *Ricinocarpus pinifolius*, *Brachyloma daphnoides*, *Dillwynia glaberrima*, *D. retorta*, *Allocasuarina distyla*, *Bossiaea ensata*, *Aotus ericoides* and *Phyllota phylicoides*. The graminoid *Empodisma minus* is generally present. The community is found sporadically northward along the coast of New South Wales from as far south as La Perouse, near Sydney, and is common in the Myall Lakes district. Within the area of the map sheet it is found in Munmorah State Recreation Area, and around Redhead (McDonald *et al.*, 1970) though much of this has been destroyed by sand-mining.

On younger, yellow, less leached sands, the open-heath is replaced by scrub with *Acacia longifolia*, *Banksia integrifolia*, *B. serrata* and *Leptospermum laevigatum*, species that appear to need the higher nutrient conditions. There may be occasional emergent trees of *Eucalyptus gummifera* and *Angophora costata*. Many of these areas have been sand-mined. *Acacia longifolia* and *Persoonia lanceolata* are conspicuous species in recolonizing areas.

Small pockets of littoral rainforest of low closed-forest structure may be found on the lee side of some of the larger dunes. Tree species here may include *Cupaniopsis anacardioides*, *Livistona australis* and *Syzygium* spp.

27a *Freshwater Swamp Complex*

This complex of communities occurs on low-lying Quaternary sediments, on floodplains or behind dune systems, and generally adjacent to areas of open water. Though essentially freshwater communities they often occur near estuarine communities (community 4a) and there may be some localized saline or brackish influence. Plant composition depends on degree of waterlogging. Permanently wet sites with standing water may have submerged or floating water plants such as *Vallisneria* and *Potamogeton* with a fringe of emergent sedges and rushes including species of *Eleocharis*, *Baumea* and *Juncus* often with *Philydrum lanuginosum*, *Alisma plantago-aquatica* and *Villarsia exalata*.

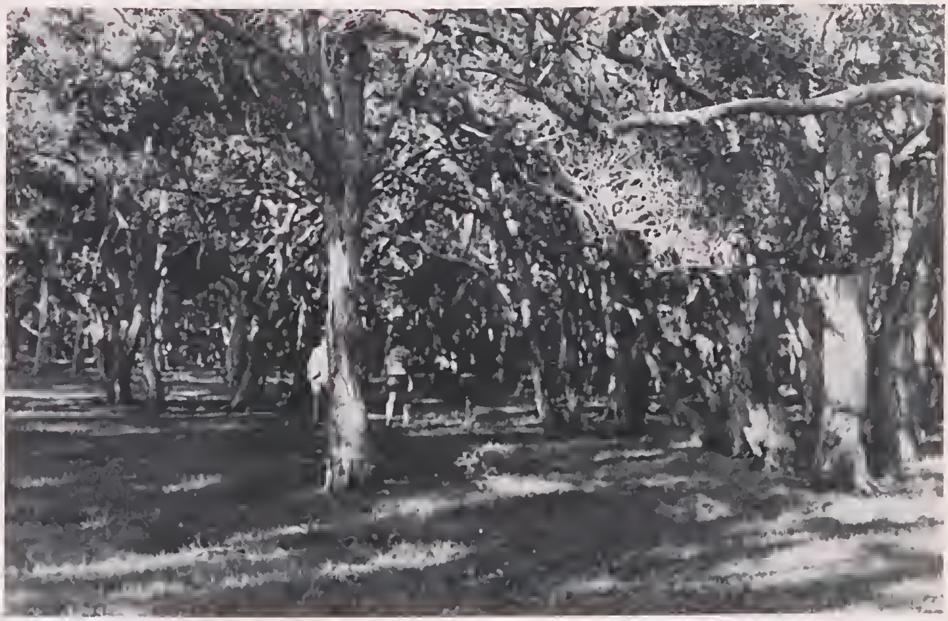

Figure 4. *Melaleuca quinquenervia* low open-forest with herbaceous understorey in Munmorah State Recreation Area (community 27a).

Brackish sites may have *Phragmites australis.* These may be surrounded by extensive open-forest with *Melaleuca quinquenervia* (Figure 4) or *Casuarina glauca*, the latter indicating brackish conditions, with an understorey of species from the wetter zones.

On adjacent drier areas may be bands of closed-heath or closed-scrub with *Melaleuca* species, *Viminaria juncea, Gahnia clarkei* and *Acacia longifolia,* or swamp forest with *Eucalyptus robusta, E. longifolia* or *E. amplifolia.*

Occasionally an open-heath community occurs on the boundary with the surrounding dry-land open-forest. Where a sizeable watercourse crosses a swamp there may be levee banks on which may be remnants of the now almost totally cleared riparian forests of *Eucalyptus pilularis, E. saligna* and *Angophora floribunda. Casuarina glauca* may form a narrow band along the edge of the levee bank adjacent to the swamp.

Freshwater swamps have been described at Toukley, Charmhaven and Fraser Park (New South Wales Department of Public Works, 1978) and Redhead, Jewels Swamp (Baxter & McDonald, undated; McDonald *et al.*, 1970; McDonald, 1971).

CONSERVATION

Species of particular conservation importance

Table 3 lists species from the Gosford/Lake Macquarie Vegetation Sheet area that are known to be rare or endangered (Leigh, Briggs & Hartley, 1981) or of significance in terms of geographic distribution of localized populations. Its purpose is to alert workers preparing environmental impact statements, plans of management, conservation studies etc., that populations of these species may be significant if they are found in their study area.

Conservation of plant communities

The major conservation areas, Dharug, Marramarra and Brisbane Water National Parks (Table 4; Figure 5) are in the south of the sheet area and mainly restricted to the vegetation of the Hawkesbury Sandstone (community 10a).

TABLE 3

Species of particular conservation importance within the Gosford and Lake Macquarie Vegetation map sheet

Species listed here are either rare or threatened (from Leigh *et al.*, 1981), or of significance in terms of geographic distribution, or localized populations disjunct from other occurrences.

pop. = population, Sth = southern, Nth = northern, NP = national park, SRA = state recreation area, NR = nature reserve.

Species	Locality/habitat	Significance (codings as in 2EC, 2V, 3V, 2RC, 3RC, Leigh *et al.*, 1981)
DICOTYLEDONS		
AIZOACEAE		
Macarthuria neocambrica	Munmorah SRA	Sth limit
ARALIACEAE		
Astrotricha crassifolia	Patonga	local pop., rare
ASTERACEAE		
Olearia cordata	Wisemans Ferry, Fernances Trig.	2V, local endemic, only 2 pop. known.
O. nernstii	Gosford	Sth limit
CONVOLVULACEAE		
Wilsonia backhousei	Saltmarsh, Wamberal Lagoon N.R.	Nth limit
CUNONIACEAE		
Caldcluvia paniculosa	Ourimbah, rainforest	Sth limit
ELAEOCARPACEAE		
Elaeocarpus obovatus	Wyong, rainforest	Sth limit
EPACRIDACEAE		
Leucopogon amplexicaulis	Brisbane Water NP	3RC, Nth limit
L. margarodes	Brisbane Water NP	Sth limit
L. pleiospermus	Woy Woy	Sth limit
Styphelia laeta var. *latifolia*	Brisbane Water NP	local pop.
FABACEAE		
Acacia bynoeana	Dora Creek, Morisset, Kulnura	rare
A. quadrilateralis	Redhead district	rare
A. prominens	Gosford district	local pop.
GOODENIACEAE		
Velleia perfoliata	Hawkesbury district	3RC
HALORAGACEAE		
Gonocarpus chinensis subsp. *verrucosa*	Hawkesbury River	rare
LAMIACEAE		
Prostanthera incisa var. *pubescens*	Kendall's Glen, Gosford	rare, possibly endemic taxon
LAURACEAE		
Endiandra discolor	Gosford district	Sth limit
MELIACEAE		
Dysoxylum fraseranum	rainforest	Sth limit
MYRSINACEAE		
Embelia australiana	Wyong District	Sth limit
MYRTACEAE		
Darwinia glaucophylla	Brisbane Water NP	2RC
D. procera	Brisbane Water NP	2RC
Decaspermum paniculatum	Ourimbah, rainforest	Sth limit

Species	Locality/habitat	Significance (codings as in 2EC, 2V, 3V, 2RC, 3RC, Leigh *et al.*, 1981)
Eucalyptus multicaulis	Brisbane Water NP	local pop.
E. luehmanniana	Brisbane Water NP	2RC Nth limit
Melaleuca deanei	Brisbane Water NP	3RC, Nth limit
Rhodomyrtus psidioides	rainforest	Sth limit
Syzigium paniculatum	littoral rainforest, Wamberal Lagoon NR	local pop.
PROTEACEAE		
Banksia paludosa	Doyalson	Nth limit
Grevillea shiressii	Brisbane Water NP	2EC
Grevillea sp. aff. *capitellata*	Brisbane Water NP	local pop.
Grevillea sp. nov.	sandstone scarp, Somersby–Narara	local endemic pop.
Hakea bakerana	Lake Macquarie district, Doyalson–Wyee, Dharug NP	uncommon
RUTACEAE		
Acronychia wilcoxiana	Gosford district	rare
Boronia fraseri	Brisbane Water NP	2RC
SAPINDACEAE		
Dodonaea megazyga	Olney State Forest	3RC, Sth limit
TREMANDRACEAE		
Tetratheca glandulosa	Mangrove Mtn–Wisemans Ferry	2RC, local pop. Nth limit.
Tetratheca juncea	Lake Macquarie district	3V, local pop.
VITIDACEAE		
Tetrastigma nitens	rainforest	Sth limit
MONOCOTYLEDONS		
JUNCAGINACEAE		
Maundia triglochinoides	Swamp, Wyong	Sth limit
LILIACEAE		
Allania endlicheri	Brisbane Water NP	3RC, local pop.
Blandfordia grandiflora	Gosford northwards	Sth limit
POACEAE		
Ancistrachne maidenii	Hawkesbury River	2RC, rare
SMILACACEAE		
Ripogonum fawcettianum	rainforest	Sth limit
XANTHORRHOEACEAE		
Xanthorrhoea resinosa subsp. *fulva*	Coastal sand systems	Sth limit
ZINGIBERACEAE		
Alpina caerulea	Martinsville	Sth limit
FERNS		
ASPLENIACEAE		
Asplenium aethiopicum	Watagan Mtns	rare
BLECHNACEAE		
Blechnum ambiguum	Brisbane Water NP	Nth limit
LINDSAEACEAE		
Lindsaea dimorpha	Brisbane Water NP	local pop., rare
OPHIOGLOSSACEAE		
Botrychium australe	Martinsville	uncommon

TABLE 4

Major conservation reserves for Gosford and Lake Macquarie 1:100 000 vegetation map sheet

Reserve	Administered by	Area (ha)	Map units included
National Parks			
Dharug NP	NP & WS	14 728	9h, 10a
Marramarra NP	NP & WS	11 503*	4a, 10a
Brisbane Water NP	NP & WS	11 151*	4a, 8a, 9h, 10a
Nature Reserves			
1. Awabakal NR	NP & WS	200	21a, 21b
2. Wamberal Lagoon NR	NP & WS	102	21b, 27a
3. Pulbah Island NR	NP & WS	69	9g
Forest Reserves			
4. Bar Forest (now a Flora Reserve)	FC	73	9g
5. Warrawolong	FC	48	6e, 9g
6. Little Jilliby Creek	FC	25	8a, 9g
7. Richters Caves	FC	24	9g
Others			
8. Munmorah State Recreation Area	NP & WS	1008	10c, 21a, 21b, 27a
9. North Entrance Nature Reserve	Wyong Shire	c800	9k

Plant community map units not conserved—8b.

* only part of this area is within the map sheet.

NP & WS = National Parks & Wildlife Service.

FC = Forestry Commission of NSW.

There are only small reserves for the conservation of other plant communities. Community 9g, a mixed eucalypt forest community, which covers approximately 80 000 ha (30% of the area covered by the map sheet) is particularly poorly protected. Apart from Pulbah Island Nature Reserve (69 ha), all other reserves are Forestry Commission Forest Preserves, with a tenure that has no legislative backing, though it is intended that these areas will eventually be declared Flora Reserves (Baur, 1981), and together total a mere 170 ha in area. As this community is particularly rich and diverse floristically, and includes significant habitat variation, these reserves are inadequate and should be increased. Increased reserves are particularly important as current forestry practices of clearing and replanting with a limited range of species, together with frequent prescribed burning, are reducing the numbers of species represented in the understorey of these forests. Indeed, one of the main requirements of the Native Forest Preservation Programme (Baur, 1981) is that Forest Preserves preferably cover an area in excess of 40 ha, though two of the four Preserves within the map area, Little Jilliby Creek (25 ha) and Richters Caves (24 ha) are considerably smaller, and a third, Warrawolong (48 ha) only just exceeds this size (Table 4). Enlargement of these forest preserves is desirable (even if the additions have been partially logged in the past) and quite possible because they are all within State Forest boundaries. Part of Little Jilliby Creek and Warrawolong Forest Preserve have already been logged, but an increase in size will help to retain a diversity of understorey species. This diversity is particularly threatened by the long-term prescribed burning programme used elsewhere in the Forests.

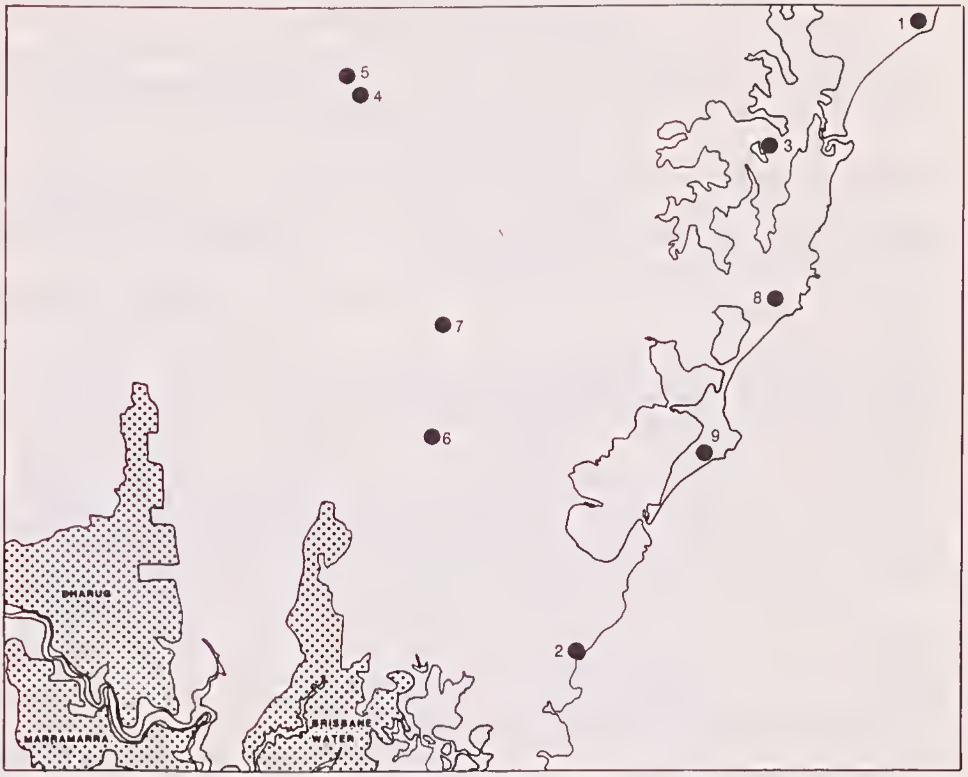

Figure 5. Location of conservation reserves mentioned in Table 4.

The conservation of some of the *Melaleuca* swamps (community 8b) is also desirable; most of these are privately owned and threatened with draining for pasture use. Similar threats face estuarine communities (community 4a) in Mangrove and Popran creeks. The National Trust of Australia (New South Wales, 1983) has proposed a Mt Olive National Park to include some of these estuarine communities as well as areas of communities 8a, 9g and 10a. The Trust has also proposed Nature Reserves for the estuarine islands, Pelican and Rileys islands, and for Mt Avoca, behind Terigal.

The New South Wales Department of Environment and Planning (1983) indicates that Rileys Island and the mainland wetlands at Empire Bay, Cockle Bay and Bensville are the most important wetland areas in Brisbane Water, the mainland ones being especially important as they are mostly privately owned and subject to potential pressures for filling and development in the longer term.

Much of the pattern of past and present land usage in the Gosford–Lake Macquarie map area can be related to the original pattern of landform and vegetation. For example, farming activities were concentrated on the wet eucalypt and rainforests of the alluvial soils, and fishing and tourist towns are associated with the estuaries. It will be a great loss if all evidence of these landform/landuse associations are destroyed. Examples of characteristics species associated with landform types are *Casuarina glauca* of the estuarine lakes, *Melaleuca* spp. of swamps, *Eucalpytus saligna* of the rich alluvial flats, *Livistona* of swamps and littoral rainforest, and *Eucalyptus maculata* of forests on poorer, dry ridges. The retention of small natural remnants of these and their associated species by the roadside, in paddocks or parks, etc., should be an important local conservation aim.

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PLANT SPECIES LISTS FROM FOUR EXCLOSURE SITES IN THE HAY DISTRICT OF SOUTH-WESTERN NEW SOUTH WALES

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ABSTRACT

Semple, W.S. (Soil Conservation Service of New South Wales, Hay, New South Wales, Australia 2711) 1986. Plant species lists from four exclosure sites in the Hay district of south-western New South Wales. Cunninghamia 1 (4): 000–000. In the early 1950s four exclosure sites were established on the Riverine Plain near Hay to study scald reclamation. The principal vegetation type in the four exclosures is an *Atriplex vesicaria* association. In this paper 269 vascular plant taxa present in the exclosures are listed. A number of these were not included in previously published species lists for the Riverine Plain.

INTRODUCTION

Since the early 1950s a number of exclosures have been established in western New South Wales by the Soil Conservation Service. Plant species lists have been published for five of the 13 exclosures currently being maintained (Cunningham & Milthorpe, 1981).

The exclosures were originally established to study reclamation of degraded lands. The main reason for establishing the four exclosures or Experimental Areas ("Jim Barren", "One Tree", "Paradise", "Tchelery") in the Hay district (Figure 1), was to evaluate and demonstrate techniques for reclaiming scalded soils.

Scalding is the name given to an erosion process that removes topsoil and exposes a smooth, compact, clayey subsoil. The resulting surface is referred to as a "scald" or colloquially, a "claypan" (a term that more accurately refers to a dry and often small lakebed (after Beadle, 1948)). Scalding, which has been attributed by many (e.g., Beadle, 1948) to wind erosion and by some (e.g., Warren, 1965) to water erosion, was the main problem facing soil conservationists in the Hay district during the 1950s. As a result of mechanical treatments (contour furrowing, waterponding and checkerboard furrowing), reseeding (commonly with *Atriplex* spp.) and natural regeneration during the good seasons of the 1950s and the early 1960s (Jones, 1966), scalds now occupy only a small proportion of each of the Experimental Areas. A brief account of the scald reclamation treatments and results has been prepared by Cunningham & Milthorpe (1976).

A variety of other studies, including run-off (Alchin, 1983), plant phenology (Alchin, unpublished data), plant-water relations (Gates & Muirhead, 1967), plant introduction (Alchin, 1974), topographic, vegetation and erosion mapping (Soil Conservation Service, unpublished data) have also been carried out in the Areas. Most of these studies had been terminated by the early 1970s.

The exclosure sites are located on or adjacent to Travelling Stock Reserves and all were originally severely eroded by scalding. The Areas are not fully representative of all soil types and plant communities in the Hay district, nor can they be regarded as examples of pristine vegetation of the land types represented in them. It should be appreciated, however, that these four Areas, together with another at Trida, 170 km to the north of Hay, are the only sizable Riverine Plain saltbush sites known to have remained ungrazed or only slightly grazed by domestic livestock for over 30 years.

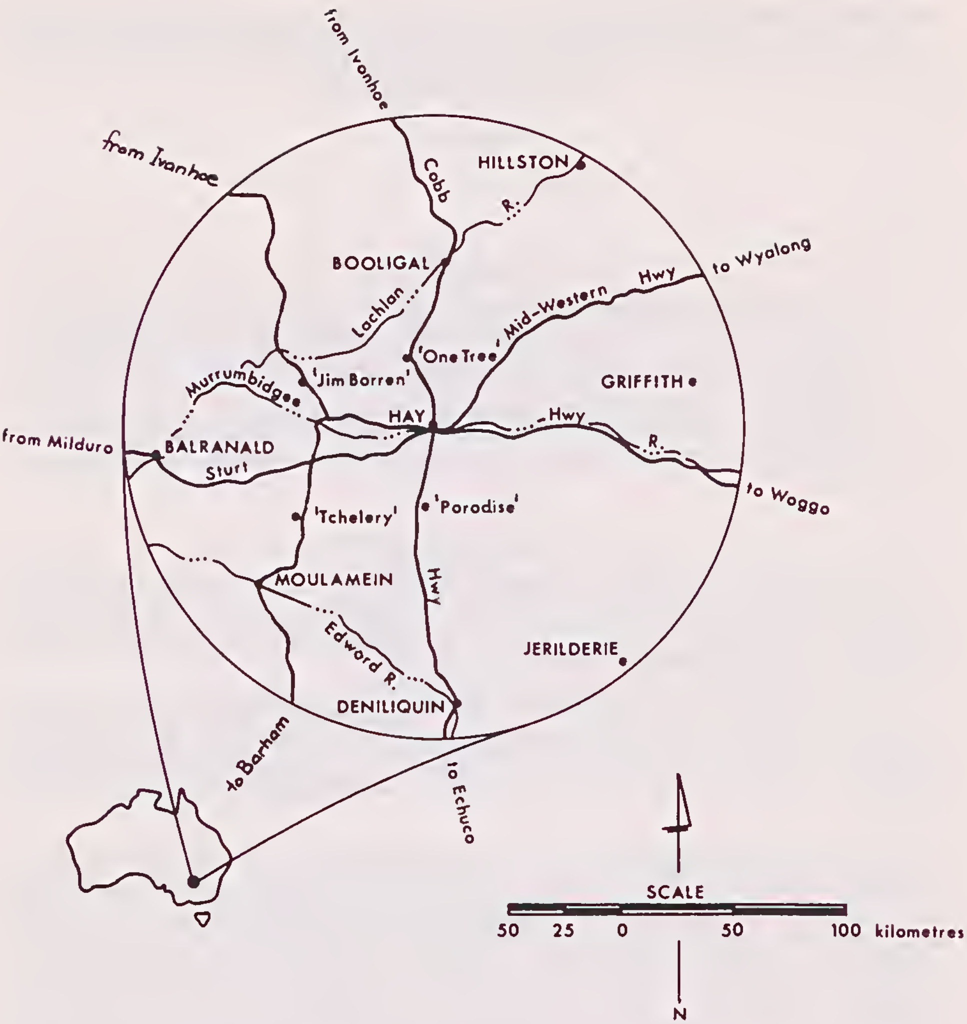

Figure 1. Location of the four exclosures: *"Jim Barren", "One Tree", "Paradise" and "Tchelery".*

DESCRIPTION OF THE AREAS

Brief descriptions of the Experimental Areas are given in Table 1. All Areas are located on the Riverine Plain of southeastern Australia, a depositional landform built up by a system of prior streams that issued from gaps in highlands to the east and south. (Butler, 1950). The long period of alluvial deposition is thought to have ceased under arid conditions during the late Pleistocene. Landform features represented on the Experimental Areas include alluvial plain, the margin of a prior stream, lunette, canegrass depression and aeolian sandhill.

The region in which the Experimental Areas are located is commonly referred to as the "Hay Plain", which comprises the well-known "One Tree Plain" to the north of Hay and the "Old Man Plain" to the south.

The principal vegetation formation on all four Areas is shrub steppe with *Atriplex vesicaria* (bladder saltbush) being the main association (Figure 2). Communities of *Maireana aphylla, M. pyramidata, Eragrostis australasica* and *Acacia homalophylla* (Figure 3) also occur on one or more of the Areas.

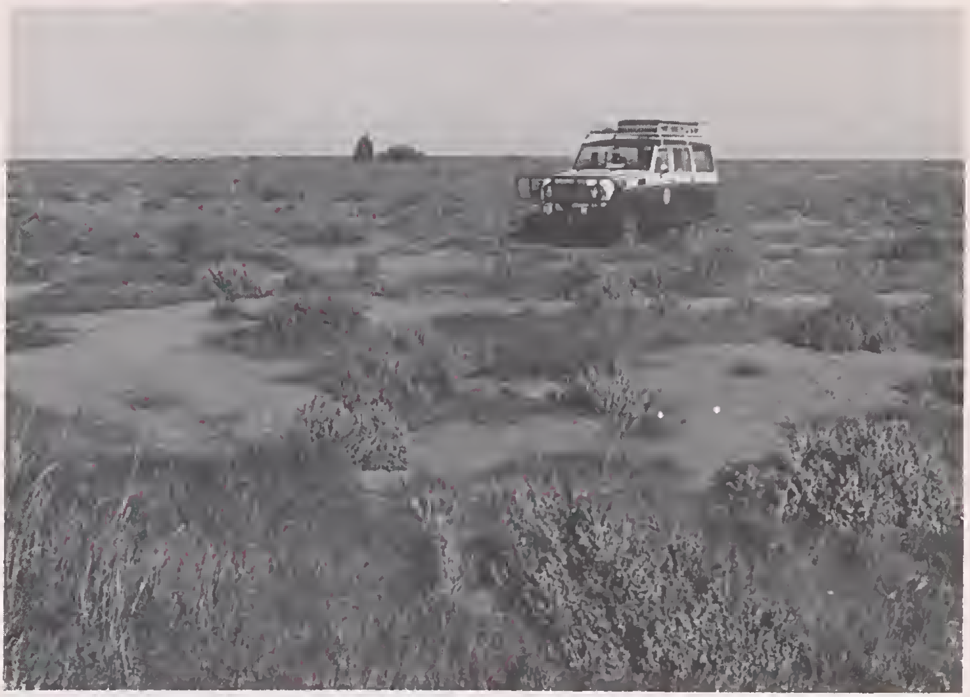

Figure 2. Stock have been excluded from this bladder saltbush (*Atriplex vesicaria*) community for over 30 years but scalds are still quite evident. Paradise Experimental Area, August 1982.

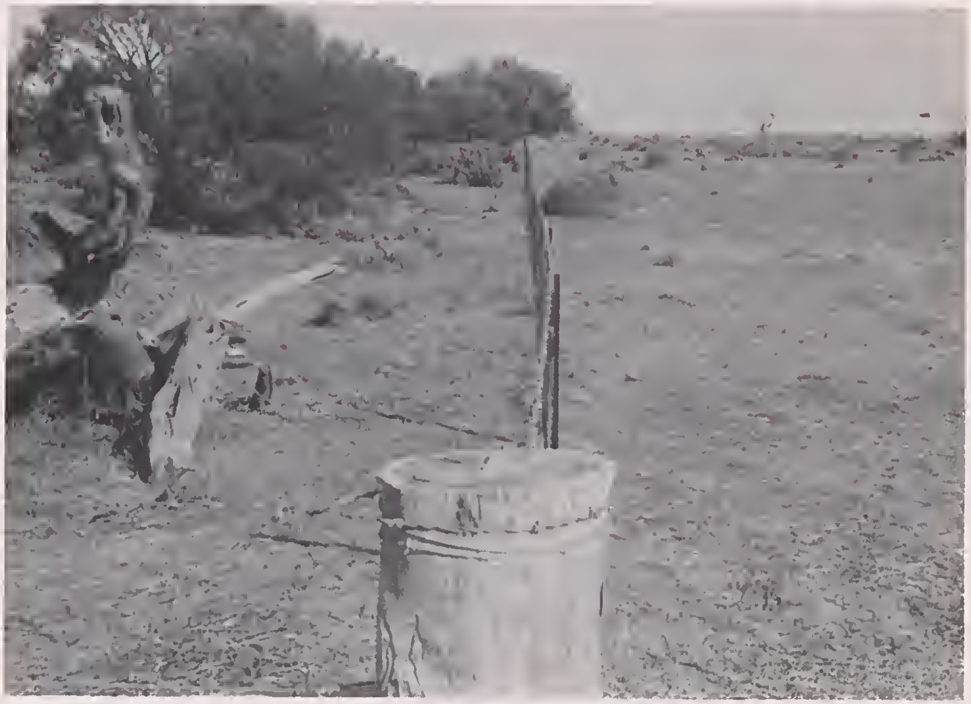

Figure 3. *Acacia homalophylla* community. Note the lack of regeneration outside the exclosure. Tchelery Experimental Area, September 1982.

TABLE 1

Brief description of the four Experimental Areas

	JIM BARREN	ONE TREE	PARADISE	TCHELERY
Approximate area (ha)	70	75	50	71
Tenure	60 ha leased from an adjoining holding, the balance occupied by agreement with the Hay Pastures Protection (P.P.) Board.	By agreement with the Hay P.P. Board.	By agreement with the Hay P.P. Board.	Reserve No. 88068 for Soil Conservation purposes.
First fenced	1952	1952	1951	1952
Landforms	* Alluvial plain with slopes commonly <0.5 per cent * Scattered low rises including small part of a lunette * Depressions	* Alluvial plain with slopes commonly <0.5 per cent * Sandy ridge up to 1.5 m above the level of the plain * Depressions	* Alluvial plain with slopes commonly <0.5 per cent * Scattered low rises (probably associated with prior stream) * Small depressions	* Alluvial plain with slopes commonly <0.5 per cent * Scattered low sandy rises and part of a larger sandy ridge about 1 m above the level of the plain
Soils (including Northcote (1971) codings where profiles have been described)	Red-brown and grey clays (e.g. Ug 5.24) and duplex soils (e.g. scalded Dy 4.13)	Red-brown and grey clays (e.g. Uf 3.1) and duplex soils	Red-brown and grey clays and duplex soils (including Dr 4.13 and scalded Db 3.13)	Red-brown and grey clays (e.g. Ug 5.38) and duplex soils (e.g. Dr 2.13)
Vegetation communities	* *Atriplex vesicaria* * *Maireana* spp. * *Eragrostis australasica*	* *Atriplex vesicaria* * *Eragrostis australasica*	* *Atriplex vesicaria* * *Maireana aphylla*	* *Atriplex vesicaria* * *Maireana aphylla* * *Acacia homalophylla*

The Experimental Areas are currently surrounded by a relatively new, conventional stock-proof fence, and each contains a recently constructed rabbit-proof exclosure of about 0.5 ha. Despite their location on well used roads and the presence of signs requesting co-operation in keeping the Areas stock-free, forced entry and subsequent grazing by domestic livestock does occasionally occur, though only for short periods, as none of the Areas contains a permanent water supply.

Efforts have been made to prevent use of the Experimental Areas by domestic and feral animals. Native animals are not deliberately excluded, but some may be hindered by the surrounding fences. Rabbits, which are a problem in only one of the Areas (Tchclery) at present, are controlled at regular intervals, usually in co-operation with the adjoining landholder. Feral pigs have been sighted on one Area (Jim Barren) only and do not currently present a problem.

Noxious plants, including *Lycium ferocissimum*, *Marrubium vulgare* and *Xanthium spinosum*, are removed or poisoned at irregular intervals.

Deliberate introductions of plants into the Areas appears to be minimal. The only successful pasture introductions were those species that were already native to the region (such as *Atriplex* spp.) or had already become naturalized (such as *Medicago truncatula*). Despite many early attempts, only a few introduced trees and tall shrubs have persisted. For completeness, these species are included, with appropriate annotation, in the species lists that follow.

The Areas have now fulfilled their original purpose of evaluating and demonstrating scald reclamation techniques. As they contain a wide variety of species in a small area, the Areas are currently used as a training ground for persons requiring knowledge of plant species in the district. As exclosures, the Areas have also been of value in the study of the widespread dieback of bladder saltbush during the late 1970s and early 1980s (Clift, Semple & Prior, unpubl. data).

THE SPECIES LISTS AND THEIR COMPILATION

Plant collections from the Areas during the 1950s and 1960s were few, but increased during the 1970s. From 1978, species were regularly recorded by the author, and many specimens were submitted to the National Herbarium of New South Wales for identification or confirmation. Duplicate specimens of all those submitted are held at the Hay office of the Soil Conservation Service.

Existing unpublished species lists for each of the Experimental Areas were examined and all observations not supported by herbarium specimens or subsequent observation were deleted. This procedure has undoubtedly resulted in the omission of some valid observations from the lists presented in Table 2. Further deletions resulted from a re-examination of herbarium specimens, many of which were later redetermined by the National Herbarium of New South Wales. It is not claimed that the species lists are complete, but it is hoped that they will provide a sound basis for subsequent additions, particularly in years of abnormally high or unseasonal rainfall.

Nomenclature in the species list is based on usage at the National Herbarium of New South Wales and largely follows Jacobs & Pickard (1981); authorities are as cited in that publication. The plants are listed in alphabetical order of families and of genera within each family.

A total of 269 species, subspecies and varieties (including one hybrid and three complexes) of native and naturalized vascular plants has been listed for the Experimental Areas. Of these, 67 (25% of the total number) are recorded as being naturalized in New South Wales (Jacobs & Pickard, 1981). Naturalized taxa are mainly from Poaceae (16 taxa), Asteraceae (19 taxa), Brassicaceae (6 taxa) and Fabaceae (8 taxa).

The listed taxa include 30% of the 876 so far published for the Riverine Plain (Leigh & Mulham, 1977; Mulham & Jones, 1981). There are 30 taxa additional to those already in published lists of native and naturalized plants; some of the additions are the result of recent generic revisions. One species, *Urospermum picroides* (L.) Desf. (Asteraceae), had not previously been recorded in New South Wales. Previous distributional data for taxa on the Riverine Plain have been extended in a number of cases.

Though all Areas consist largely of the *Atriplex vesicaria* association, there is much floristic variation between them (Table 2). Only 79 taxa, out of a total of 269, are common to all Areas. The presence of different landform features and small localized habitats on each Area would account for much of this variation; however, more frequent observations on the more accessible Areas such as "Paradise", is another probable contributor.

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Without the assistance of the staff of the National Herbarium of New South Wales, this paper would not have been possible. The assistance of Mr W. E. Mulham of the CSIRO Division of Wildlife and Rangelands Research and Messrs P. J. Walker and D. J. Eldridge of the Soil Conservation Service of New South Wales with nomenclature, editing the manuscript and soil descriptions, is gratefully acknowledged.

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TABLE 2

Vascular plants recorded from four exclosures in the Hay district

X = observed in Experimental Area (without voucher)
V = voucher specimen from Experimental Area held at Hay S.C.S. office
+ = species deliberately planted in Experimental Area
* = species naturalized in New South Wales (after Jacobs & Pickard, 1981)
# = not included in previously published lists for the Riverine Plain (Leigh & Mulham, 1977; Mulham & Jones, 1981)

Botanical Name	Jim Barren	One Tree	Paradise	Tchelery
PTERIDOPHYTES				
Adiantaceae				
Cheilanthes sp.	—	—	X	—
Marsileaceae				
Marsilea drummondii	X	X	X	X
GYMNOSPERMS				
Cupressaceae				
Callitris glaucophylla	—	—	—	X
ANGIOSPERMS				
Aizoaceae				
Disphyma clavellatum	X	V	—	—
Sarcozona praecox	—	V	V	X
Tetragonia tetragonioides	X	X	X	X
Zaleya galericulata	—	V	—	—
Amaranthaceae				
#**Alternanthera angustifolia*	—	V	V	V
A. denticulata	—	—	—	V
Amaranthus macrocarpus	—	V	V	V
Ptilotus spathulatus	—	—	V	—
Apiaceae				
Daucus glochidiatus	V	V	V	X
Asteraceae				
Actinobole uliginosum	—	—	—	V
**Arctotheca calendula*	—	X	X	X
Brachycome campylocarpa	V	V	V	X
#*B. ciliaris* var. *ciliaris*	V	—	—	—
#*B.* sp. aff. *ciliocarpa*	V	—	—	—
B. curvicarpa	—	—	—	V
B. lineariloba	V	V	V	V
B. papillosa	V	—	—	—
Calocephalus sonderi	X	X	V	X
Calotis hispidula	V	V	X	V
C. scabiosifolia	—	V	V	—
**Carduus tenuiflorus* (complex)	V	—	—	—
**Carthamus lanatus*	X	X	X	—
**Centaurea melitensis*	V	X	X	X
Centipeda cunninghamii	X	V	—	—
C. thespidioides	—	V	—	V
**Chondrilla juncea*	—	—	V	—
**Cirsium vulgare*	X	X	X	X
**Conyza albida*	—	—	—	V
**C. bonariensis*	—	—	V	X
**Cotula bipinnata*	—	V	V	—
C. coronopifolia	—	V	—	—
Craspedia pleiocephala	V	—	—	V
C. globosa	—	—	V	—
Eriochlamys behrii	—	—	—	V
#*Gnaphalium sphaericum*	—	—	V	—
**Hedypnois rhagodioloides* ssp. *cretica*	V	X	V	V
Helipterum corymbiflorum	X	X	V	V
#*H. diffusum*	—	—	V	—
H. floribundum	V	V	V	V
H. hyalospermum	—	—	—	V
H. jessenii	—	—	V	—
H. moschatum	—	V	—	V

Botanical Name	Jim Barren	One Tree	Paradise	Tchclery
H. praecox	—	—	—	V
H. pygmaeum	X	—	V	V
*_Hypochoeris glabra_	V	V	—	X
*_H. radicata_	—	—	V	—
Ixiolaena leptolepis	V	V	V	V
*_Lactuca serriola_	X	V	V	—
Leptorhynchos panaetioides	V	V	V	V
Microseris lanceolata	—	V	V	—
Minuria cunninghamii	V	V	V	V
M. denticulata	V	V	V	V
M. integerrima	—	—	V	—
M. leptophylla	X	V	V	V
Myriocephalus rhizocephalus var. _rhizocephalus_	—	—	—	V
#_M. stuartii_	V	—	—	—
*_Onopordum acaulon_	V	—	—	—
*_Picris echioides_	—	—	V	V
Podolepis muelleri	—	—	V	X
*_Podospermum resedifolium_	V	—	V	—
Pogonolepis stricta	—	—	V	V
Senecio cunninghamii	X	X	—	—
S. glossanthus	V	V	V	V
#_S. lautus_ ssp. _dissectifolius_	—	V	—	—
S. quadridentatus	—	V	—	—
S. runcinifolius	X	V	X	V
*_Sonchus oleraceus_	V	V	X	X
#*_Urospermum picroides_	V	—	—	—
Vittadinia pterochaeta	—	—	—	V
_V._ sp. _B_ (_V. conydyloides_)	—	V	—	—
#_V._ sp. _E_ (_V. gracilis_)	—	—	V	—
*_Xanthium spinosum_	X	X	—	X
Boraginaceae				
*_Echium plantagineum_	X	X	X	X
*_Heliotropium europaeum_	V	—	V	V
Plagiobothrys plurisepaleus	—	—	—	V
Brassicaceae				
Arabidella nasturtium	V	—	V	X
*_Brassica tournefortii_	—	X	X	X
*_Capsella bursa-pastoris_	—	X	X	—
#_Cuphonotus humistratus_	—	—	—	V
#_Harmsiodoxa brevipes_ var. _brevipes_	—	V	—	V
*_Lepidium africanum_	—	V	V	—
L. fasciculatum	V	V	—	X
L. papillosum	V	—	—	—
#_L. pseudohyssopifolium_ (_L._ sp. _A_)	—	—	V	—
#_L. sagittulatum_	—	V	V	—
Menkea australis	—	—	V	—
*_Sisymbrium erysimoides_	X	X	V	V
*_S. irio_	X	X	X	—
*_S. orientale_	V	V	V	X
Caesalpiniaceae				
Cassia eremophila var. _eremophila_	—	—	—	X
Campanulaceae				
Wahlenbergia communis	—	—	—	V
W. fluminalis	—	—	V	V
#_W. gracilenta_	—	—	V	—
#_W. gracilis_	—	—	—	V
Caryophyllaceae				
*_Spergularia diandra_	—	—	—	V
*_S. rubra_	V	V	V	X
Chenopodiaceae				
Atriplex conduplicata	X	V	—	—
A. eardleyi	—	—	—	V
A. holocarpa	V	V	—	—

Botanical name	Jim Barren	One Tree	Paradise	Tchelery
A. leptocarpa	—	—	X	X
A. lindleyi	V	V	X	X
A. nummularia	X	X	X	X
A. pseudocampanulata	V	V	X	X
A. semibaccata	V	—	X	X
A. vesicaria	X	X	V	X
#*Chenopodium cristatum*	—	—	V	—
**C. murale*	—	—	—	V
C. nitrariaceum	X	X	X	X
#*C. pumilio*	—	—	V	V
Dissocarpus biflorus	V	X	—	X
Einadia nutans	X	X	V	X
Enchylaena tomentosa	V	—	—	X
Maireana aphylla	—	X	X	X
#*M. apressa*	V	V	—	—
M. brevifolia	—	—	—	V
M. cheelii	—	—	V	V
#*M. coronata*	—	—	V	—
M. decalvans	—	—	V	—
M. microcarpa	V	V	—	—
M. pentagona	—	—	V	V
M. pyramidata	X	X	X	X
#*M. tomentosa*	—	—	V	—
#*M. turbinata*	—	V	—	V
Malacocera tricornis	X	X	X	X
Osteocarpum acropterum	V	X	X	V
Rhagodia spinescens	X	X	V	X
Salsola kali	X	X	V	X
Sclerobliturn atriplicinum	V	V	—	X
Sclerolaena diacantha	—	—	V	V
S. divaricata	X	V	X	X
S. intricata	X	V	X	X
S. muricata	V	V	V	X
S. tricuspis	X	X	V	X
S. sp. *A* (*Bassia brachyptera*)	X	X	X	V
S. sp. *B* (*Bassia stelligera*)	—	—	V	V
Sclerostegia tenuis	V	X	X	V
Convolvulaceae				
Convolvulus erubescens	X	V	X	V
Cressa cretica	—	—	—	V
Crassulaceae				
#*Crassula colorata* var. *tuberculata*	V	V	—	—
C. sieberiana	X	X	V	V
Cucurbitaceae				
**Citrullus lanatus*	—	X	—	X
**Cucumis myriocarpus*	—	—	—	V
Cyperaceae				
Eleocharis acuta	—	—	—	V
E. pallens	V	X	X	—
Euphorbiaceae				
Chamaesyce drummondii	V	X	V	V
Euphorbia eremophila	—	X	—	—
Fabaceae				
Lotus cruentus	—	V	—	V
**Medicago laciniata*	V	V	—	V
**M. minima*	V	V	V	X
**M. polymorpha* var. *vulgaris*	V	V	V	X
**M. praecox*	V	X	V	—
**M. truncatula*	X	X	V	X
**Trifolium arvense*	—	—	V	—

Botanical name	Jim Barren	One Tree	Paradise	Tchelery
**T. glomeratum*	X	—	X	X
**T. tomentosum*	X	—	X	X
Frankeniaceae				
Frankenia connata	—	V	—	—
Gentianaceae				
Centaurium spicatum	V	V	V	—
Geraniaceae				
Erodium cicutarium	X	V	V	V
E. crinitum	V	X	V	V
**E. moschatum*	—	—	V	V
Goodeniaceae				
Goodenia fascicularis	—	V	—	V
G. glauca	V	—	—	—
G. pinnatifida	—	V	V	—
G. pusilliflora	—	—	V	V
Hypoxidaceae				
#*Hypoxis hygrometrica*	—	—	—	V
H. hookeri (pusilla)	—	—	V	—
Juncaceae				
Juncus aridicola	V	V	V	—
#*J. aridicola* x *J. subglaucus*	V	—	—	—
J. bufonius	V	X	V	X
J flavidus	—	—	V	—
J. radula	—	V	V	V
Lamiaceae				
**Marrubium vulgare*	—	X	—	X
Teucrium racemosum	—	—	—	V
Liliaceae				
Wurmbea dioica (Anguillaria dioca)	—	—	—	V
Bulbine semibarbata	V	V	V	X
#*Thysanotus baueri*	—	—	—	V
Loranthaceae				
Amyema quandang var. *quandang*	—	—	—	V
Lythraceae				
Lythrum hyssopifolia	V	V	—	—
Malvaceae				
Abutilon halophilum	—	—	V	—
#*A. otocarpum*	—	—	—	V
Hibiscus trionum	—	—	—	V
Lavatera plebeia	X	X	V	X
**Malva parviflora*	V	X	V	V
Sida intricata	—	—	—	V
Sida trichopoda	—	—	V	—
Mimosaceae				
+*Acacia brachystachya*	—	—	V	V
A. homalophylla	—	—	—	V
A. oswaldii	—	—	—	V
A. salicina	—	—	—	V
Myoporaceae				
+*Eremophila bignoniiflora*	—	—	—	V
E. longifolia	—	—	—	X
Myrtaceae				
+*Eucalyptus camaldulensis*	—	V	V	—
+*E. dundasii*	—	—	V	—
+*E. flocktoniae*	—	V	—	—
+*E. populnea*	—	—	—	X
+*E. woodwardii*	—	V	—	—

Botanical name	Jim Barren	One Tree	Paradise	Tchelery
Nyctaginaceae				
Boerhavia coccinea	—	—	V	V
Onagraceae				
Epilobium billardierianum ssp. *cinereum*	—	—	V	—
Oxalidaceae				
Oxalis corniculata (complex)	X	X	V	V
Plantaginaceae				
Plantago cunninghamii	V	X	V	V
P. drummondii	—	V	V	—
P. turrifera	—	X	—	V
Poaceae				
Agrostis avenacea	V	V	X	X
**Alopecurus geniculatus*	V	V	—	V
Amphibromus nervosus	—	—	V	—
**Avena fatua*	X	X	X	X
Bromus arenarius	X	V	X	X
**B. molliformis*	—	V	V	V
**B. rubens*	V	V	X	V
**B. unioloides*	—	—	—	V
Chloris acicularis	X	X	X	X
C. truncata	X	V	X	X
Dactyloctenium radulans	—	X	V	V
Danthonia auriculata	—	—	V	—
D. caespitosa	X	X	V	V
D. setacea	—	V	V	—
Diplachne fusca	—	V	V	V
Eragrostis australasica	X	X	X	X
#*E. molybdea*	—	—	—	V
E. parviflora	V	—	V	V
E. setifolia	—	—	—	V
Eriochloa crebra	—	—	V	—
E. pseudoacrotricha	—	—	V	—
**Hordeum leporinum*	V	V	X	X
**H. marinum*	V	V	X	X
**Lamarckia aurea*	X	V	X	X
**Lolium perenne*	—	V	—	—
**L. rigidum*	V	—	X	V
Panicum prolutum	V	—	—	—
P. whitei	—	—	V	—
**Parapholis incurva*	X	X	V	V
**Phalaris minor*	V	V	V	V
**P. paradoxa*	V	V	V	—
Poa fordeana	—	V	—	—
Puccinellia stricta	V	—	—	—
**Schismus barbatus*	V	V	X	X
Sporobolus caroli	V	X	V	X
Stipa elegantissima	V	—	—	—
S. variabilis (complex)	X	X	X	X
Tragus australianus	—	V	V	X
#**Vulpia bromoides*	—	—	V	—
**V. myuros*	V	V	V	V
Polygonaceae				
Muehlenbeckia cunninghamii	—	—	X	X
M. horrida	—	—	V	—
**Polygonum aviculare*	—	X	X	—
Rumex brownii	—	—	V	—
**R. crispus*	—	—	V	—
R. dumosus	—	—	V	—
R. tenax	—	—	—	V

Botanical name	Jim Barren	One Tree	Paradise	Tchelery
Portulacaceae				
Calandrinia eremaea	—	—	V	X
C. pumila	—	—	—	X
C. volubilis	—	V	V	X
Portulaca oleracea	X	V	V	X
Proteaceae				
Hakea leucoptera	—	—	—	X
Ranunculaceae				
**Myosurus minimus*	V	X	X	X
Ranunculus pentandrus var. *platycarpus*	V	X	X	X
Rubiaceae				
Asperula conferta	—	—	V	—
Santalaceae				
Exocarpos aphyllus	—	—	—	V
Sapindaceae				
Dodonaea viscosa ssp. *angustissima*	—	V	—	X
Scrophulariaceae				
Glossostigma sp.	V	—	—	—
Limosella curdieana	X	X	V	V
Solanaceae				
**Lycium ferocissimum*	X	X	X	X
Solanum esuriale	X	V	V	X
**S. nigrum*	—	—	—	V
Urticaceae				
Urtica incisa	—	—	—	V
**U. urens*	—	—	—	V
Verbenanceae				
**Verbena supina*	—	V	—	—
Zygophyllaceae				
Nitraria billardieri	V	X	X	X
Tribulus terrestris	—	V	V	X
Zygophyllum glaucum	—	—	V	V
Z. iodocarpum	V	V	—	V
#Z. sp. *A.* (aff. *ammophilum*)	V	—	—	—
#Z. sp. *C.* (aff. *billardieri*)	—	—	V	—
Total taxa (excluding deliberate plantings)	130	147	171	181

Cunninghamia 1(4), 503–536 (1986)

ALGAE OF THE PEEL RIVER AND THE NEWLY CONSTRUCTED CHAFFEY DAM, NEW SOUTH WALES, AUSTRALIA

Valerie May & J. M. Powell

(Accepted for publication 21.2.1986)

ABSTRACT

May, Valerie & Powell, J.M. (National Herbarium of New South Wales, Royal Botanic Gardens, Sydney, Australia, 2000) 1986. Algae of the Peel River and the newly constructed Chaffey Dam, New South Wales, Australia. Cunninghamia 1(4): 503–536. The algal floras of the Upper Peel River above and below Chaffey Dam were studied between October 1977 and September 1981, and the algal flora of Chaffey Dam surveyed from October 1979, to investigate some of the biological changes induced by the formation of a dam in a river. Seventy-two taxa were recorded; 42 were present in all areas, 24 were found only in the River and one was restricted to the Dam. Changes in the presence of individual taxa and in their frequency, abundance, duration of occurrence and seasonality were found to be related to changes in waterflow, differences in water depth and temperature, and availability of nutrients. Successional changes may have contributed to some changes within the Dam. Colonization was more or less concurrent throughout the Dam, and there was a general increase in the number of species over time. Some taxa appeared to be favoured by the habitat conditions of the Dam, but others were more obviously fluvial. In all areas the number of species increased during drought and while some taxa were favoured at such times, others flourished more during times of normal waterflow. Long-term, detailed studies of river and lake floras are needed to provide a sound base for the use of algae in biological surveillance.

INTRODUCTION

There is a need for detailed and prolonged studies of aquatic flora and fauna. Williams (1976) has emphasized the lack of basic ecological data for most Australian inland aquatic environments, whilst Bowen & Smalls (1980) remark that “few data exist which indicate the nature of changes taking place in Australian reservoirs during the initial phases of their existence”. Lund (cited in Smalls,1978), discussing a blue-green alga (also known as a Cyanobacterium), says “observations over a single year may give a false idea of the changes taking place”, and Youngman (cited in Smalls,1978) noted that results had differed each year in the reservoir he studied from 1965 to 1973. Bowen & Smalls (1980) studied the phytoplankton of Prospect Reservoir in 1964 and again in 1977; they found that increased eutrophication was reflected by changes in both the nature and density of the algal crop.

This study began in 1977 when collections of the algae of the Peel River were started, two years before Chaffey Dam was completed. Study of the dam is continuing. The aim is to record the algal flora of a river and to monitor any changes in the flora caused by the formation of a dam. In this paper the results of the first four years of study are reported. Details are given of changes in the floras of mainly microscopic algae and in the distribution of a few macrophytes, (a) in the River above the Dam over a period of four years, (b) within the newly formed Dam over two years, and (c) in the River below the Dam over four years, including the period of construction and functioning of the Dam. This forms the first Australian study in such detail; the significance of the algal investigation is enhanced by the concurrent physio-chemical studies by officers of the Water Resources Commission of New South Wales, and by observations on the less readily identified diatoms, reported by Holland (Appendix 2).

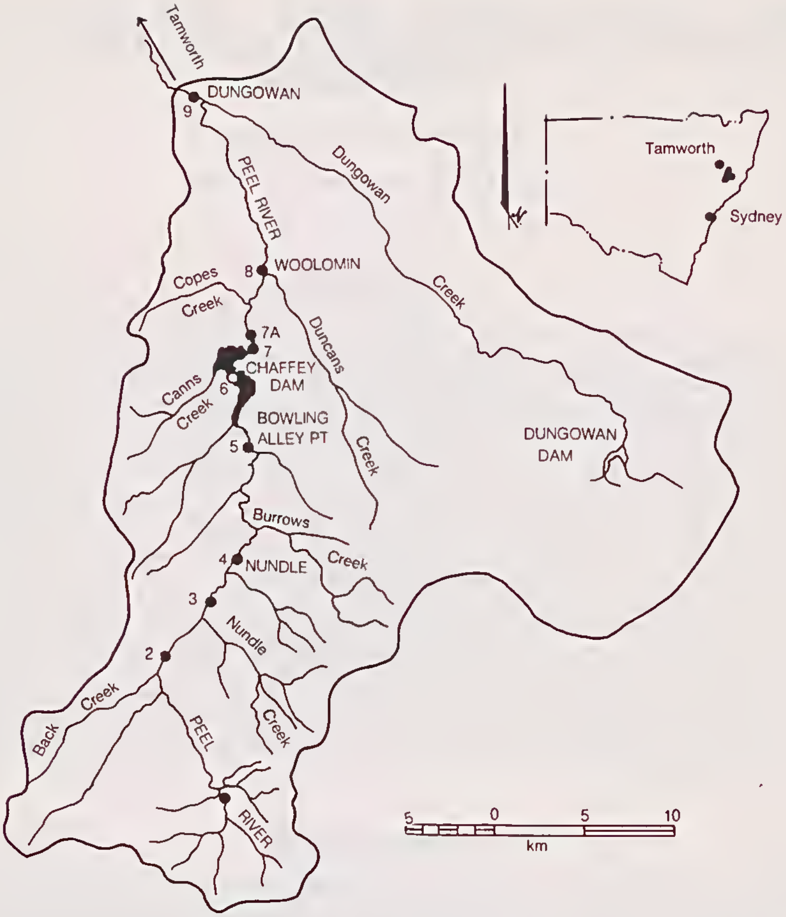

Figure 1. Location of Peel River and Chaffey Dam showing collecting stations on the Peel River.

The study area and monitored stations

The Peel River runs north from the relatively undisturbed natural vegetation and pastoral land areas of the Great Divide on the Northern Tablelands of New South Wales and flows into the Namoi River and thence into the western drainage system of New South Wales. Chaffey Dam, at 31°33′S, 151°12′E is north of Nundle township (32 km south of Tamworth; Figure 1).

In 1977 ten stations were set up for monitoring along the Peel River. Five of these (1–5) were located upstream from the Dam site, while station 6 was engulfed during Dam construction; records from this station are available for the first two years only. The other four river stations (7, 7A, 8, 9) were downstream of the Dam site (Figure 1). In 1979 five stations were established within Chaffey Dam itself (Figure 2A).

The flow of the Peel River above Chaffey Dam is extremely variable. At times of normal rainfall there is an inflow of water from numerous small tributaries and water depths at the monitored stations range from 0.5 to 1.0 metres. Station 4 also receives septic tank and other drainage from Nundle.

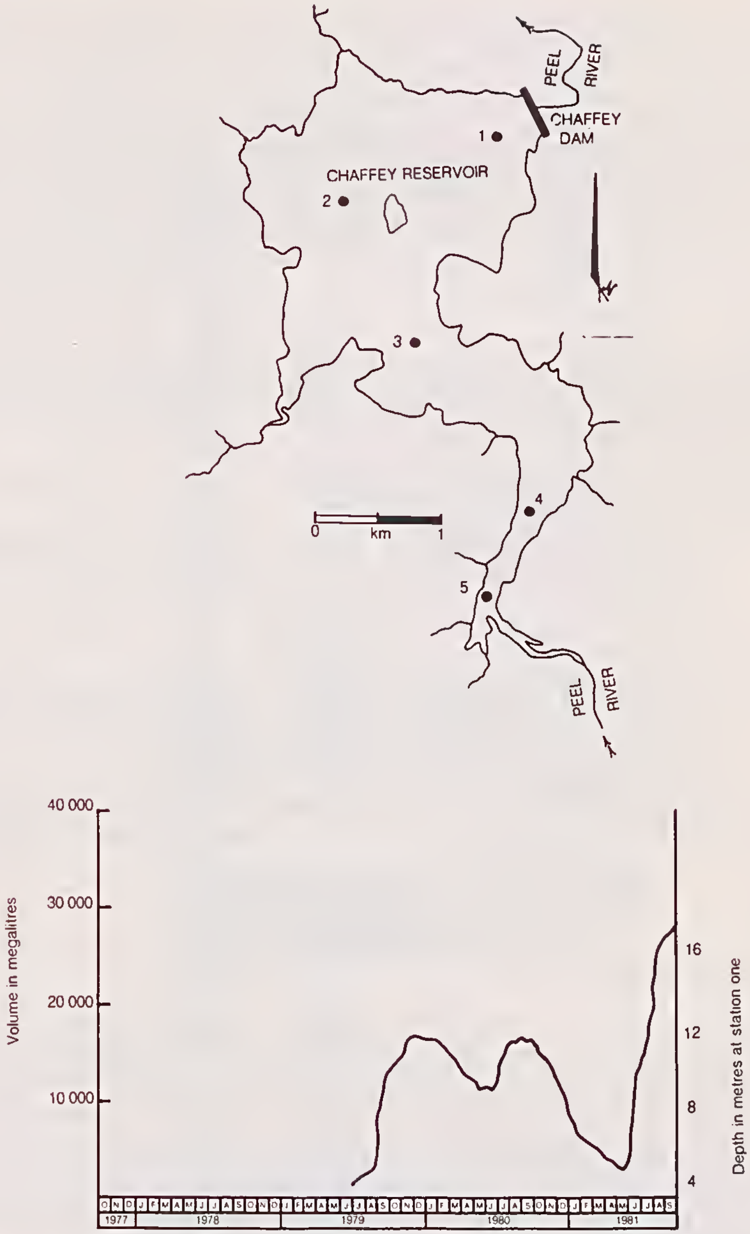

Figure 2. Chaffey Dam: (A) Locations of stations; (B) Volume of storage and approximate depth at station 1.

During droughts the volume of water is greatly reduced and some tributaries become stagnant and/or dry. During summer and autumn of both 1980 and 1981, the most severe periods of drought during the present study, water continued to flow only at station 4.

Construction of Chaffey Dam began before 1977, but the river flow was not affected until April 1979. The filling of the Dam was delayed by drought and even by September 1981 it was not full. At the five Dam stations (Figure 2A) low water depths restricted sampling over much of the study period and at station 5 water depth was insufficient for collection until August and September 1981. The data from this station are discussed but not included in the Figures. Water levels were affected by flow out of, as well as into, the Dam, water being released intermittently after 11 December 1979. At Dam station 1 between October 1979 and October 1980, water depth ranged between nine and 12 metres, with the lowest recordings in March and April. After October 1980 the depth gradually dropped to six metres by February 1981, remained between five and six metres until the end of May and then began to rise, to 11 metres by June, 15 metres by July 1981. Water depth remained between 15 and 16 metres from then until the end of the present observations (Figure 2B). The stations first covered by water were earlier in developing conditions pertaining to a dam rather than a river and, being deeper, were less affected by the drought.

After October 1979 intermittent aeration was applied whenever the temperature difference between top and bottom water equalled or exceeded four Centigrade degrees and/or the dissolved oxygen fell below 2 mg per litre. This achieved artificial overturn at the time.

River stations 7, 7A, 8 and 9, downstream of Chaffey Dam (Figure 1) were subjected to a number of different conditions:

(1) between 28 September 1977 and 20 March 1979, drainage was affected by soil disturbance from Dam construction, but there was no interference with the water flow,

(2) between 20 March 1979 and 26 June 1979, the flow of the River was partly impeded as the Dam filled,

(3) between 16 July and 11 December 1979, the Dam outlet prevented all water flow, and water levels immediately below the Dam wall dropped rapidly; flow continued at stations 8 and 9, however, as they received water from tributaries (Figure 1),

(4) after 11 December 1979, intermittent releases of water allowed a slow flow downstream of the Dam despite drought conditions.

METHODS

Collection of samples

Water samples were collected in a five-litre perspex free-flow sampler at fortnightly or monthly intervals between October 1977 and September 1981 at the River stations and between October 1979 and September 1981 at the Dam stations given that sufficient water was present to allow flow. Samples taken at river stations were from the surface region of well-mixed running water, while those from the dam stations were from three depths: top (surface), bottom (near the sediment), and middle or from the thermocline when present. The thermocline was determined by measuring temperatures. The attached algae and angiosperms at each station were collected separately.

Two 100 ml sub-samples were taken from the original five litre sample for examination of planktonic algae; one sub-sample was preserved in Lugol's solution immediately, the other was packed with iced "bricks" in an insulated container and transferred to the laboratory as quickly as possible, usually within two days.

Analysis of samples

The non-preserved sub-sample was shaken and filtered, the algae being washed to the base of the filter paper during the process, and then mounted on a slide for immediate examination. If the non-preserved sample was damaged in transit, the Lugol's material was used. The filter paper was examined for any

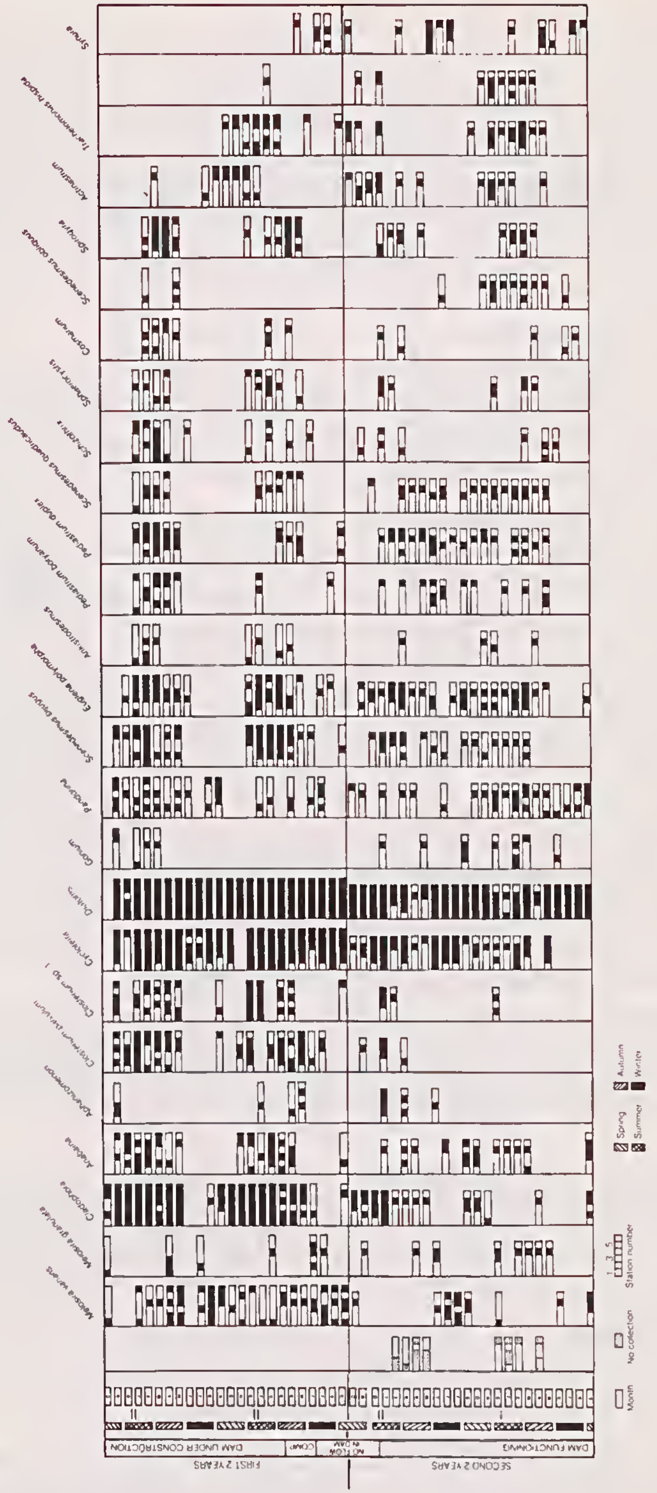

Figure 3. Occurrence of common taxa at stations 1–6 in the Peel River above Chaffey Dam. On the left hand side of the diagram the periods of construction and functioning of the Dam are shown together with the seasons, years, calendar months, and times of restricted water sampling.

remaining algae (for example, clumps of *Anacystis* if in bloom, or other larger species) and these were noted. The slides were studied at magnifications of 40 to 200x using a binocular compound microscope. The species present were recorded and the numbers of each taxon obtained by counting taxa along traverses of the slide. These figures formed the basis for estimating abundance. The following ratings were used: high—more than 50 per mm², medium—5–50 per mm², and low—less than 5 per mm². With colonies such as *Anacystis*, or larger-growing species such as *Volvox*, a subjective estimate was made; this was normally an underestimate as some material may have remained on the filter paper, as discussed above. Attached algae and drift material of larger plants (in the Dam study) were recorded merely as present.

Presentation and interpretation of data

Where only one species of a genus is reported in this study, the generic name alone is used. A full list of species names and authorities is given in Appendix 1. Only a few diatom taxa were identified (*Melosira, Cyclotella, Asterionella*), others being grouped as "Diatoms"; they are discussed more fully by Holland (Appendix 2).

Sampling at fortnightly intervals usually gave little, if any, additional information over monthly sampling and so the data are presented as monthly records. The data obtained for each taxon were sorted and plotted, in order of first occurrence at any station. Trends and changes in the plant populations could then be considered. Frequency and seasonal comparisons are based on the monthly data. The term "seasonality" refers to the range of seasons over which the taxon occurred within a defined time period (of 18 months, 2 years, etc.) whilst "duration of occurrence" refers to the total period of time (in number of months, not necessarily sequential) that the taxon was present within the defined time period. Frequency was calculated as the actual number of occurrences divided by the maximum theoretical number of occurrences and expressed as a percentage. The abundance data are expressed as the number of station-months that the taxon was recorded with medium or high abundance ratings. In interpreting these data any occasional low or high reading is not considered important, since a local change of environmental conditions, for example, a change of wind or a flush of water, can cause quite different concentrations of planktonic algae. A single occurrence noted some months apart from others is regarded as a chance occurrence.

The data on rare species (defined as being present on only 5 per cent or less of the total station-months recorded in each region) are graphed separately from the common species, and less detailed information is given on them; full records are deposited in the library of the National Herbarium of New South Wales.

The data for the different regions of the River (above and below the Dam site) and for the Dam itself are presented separately. The times of restricted sampling due to low water levels and the periods of construction and functioning of the Dam, relevant for comparative discussions, are shown also. The floras of the three regions are then compared, with similarities and differences discussed.

RESULTS

Algae occurring in the Peel River above Chaffey Dam

River stations 1–5 were unaffected by the Dam construction, so the four years of observation provide a good basis for discussion of the behaviour of the various algal taxa found there (Figures 3–5). The records from station 6, which was engulfed during the Dam construction, did not differ greatly from those of stations 1–5 and are included for the first 2-year period. The observations are

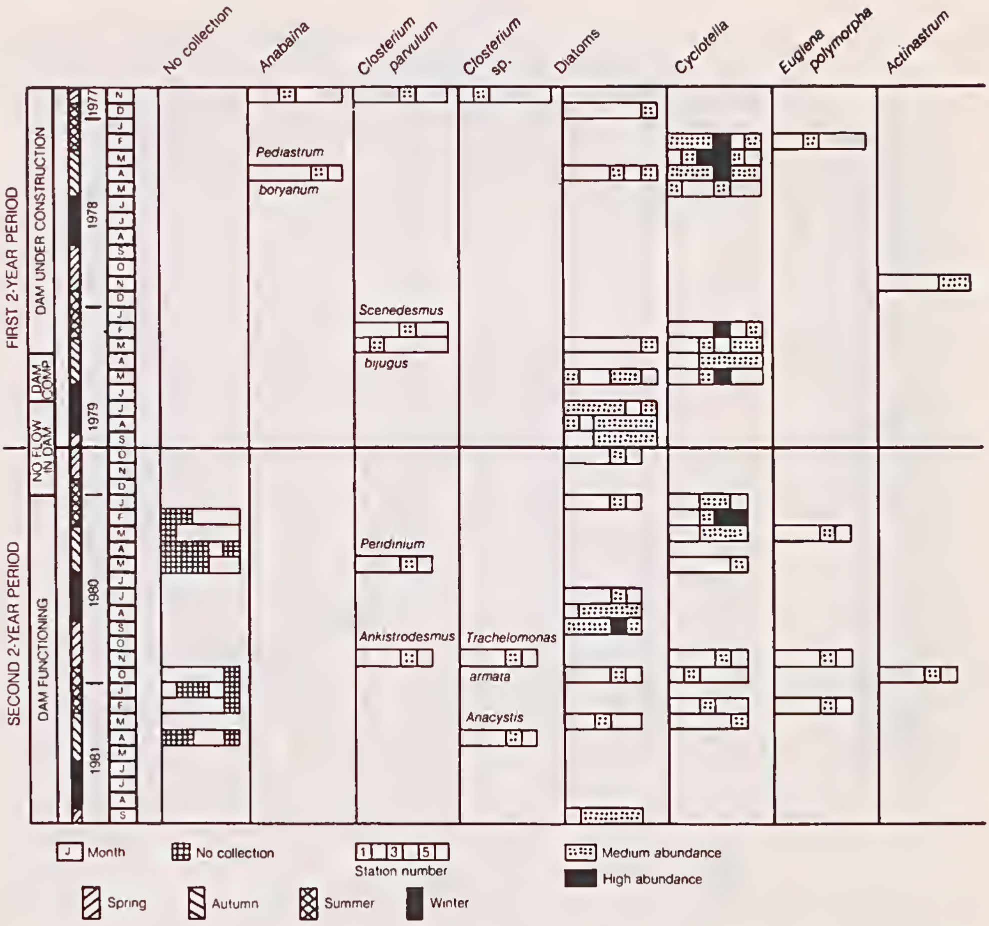

Figure 4. Abundance ratings for taxa at stations in the Peel River above Chaffey Dam. Taxa with only 1 to 2 occurrences are plotted together on the left of Diatoms. On the left hand side of the diagram the periods of construction and functioning of the Dam are shown together with the seasons, years, calendar months and times of restricted water sampling.

considered in two equal time periods: (a) from October 1977 to September 1979, during normal river flow; (b) from October 1979 to September 1981, including the periods of drought.

Species composition

Fifty-seven taxa were recorded at these stations, 37 of which were found during both time periods. Four taxa were found only within the first 2 years (1977–1979), and 16 others only within the second 2-year period (1979-1981; Figures 3, 5). One of the latter group, *Anacystis*, was recorded as abundant (Figure 4).

Of the 37 taxa found during both time periods, 11 were rare (frequency of 5 per cent or less); they occurred on less than 12 occasions in any station over the four years and often at only one station at any particular time (Figure 5). One, *Peridinium*, was recorded as abundant once (Figure 4). Twenty-six taxa were common (Figure 3) and of these 11 recorded medium or high abundance

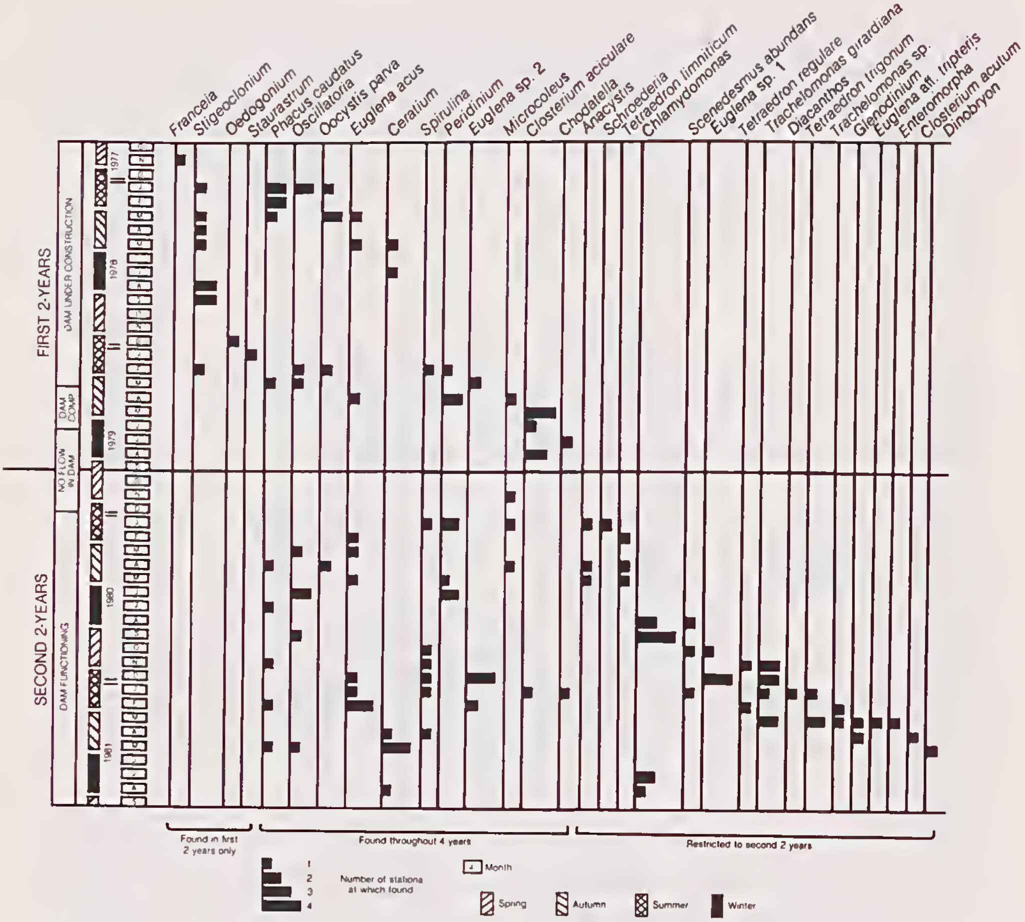

Figure 5. Occurrence of rare species at stations in the Peel River above Chaffey Dam. Only the total number of stations at which each species was found is given. Data on the left are shown as in Figure 3 except for the times of restricted water sampling.

ratings on one or more occasions (Figure 4). The data on duration of occurrence and frequency for all taxa are summarized in Tables 1 and 2, with abundance data for the common taxa included also in Table 1.

The data indicate that:

(1) more species occurred during the second 2-year period than the first (53 compared with 41; Figures 3, 5)

(2) more species showed higher frequencies in that second 2-year period (22 compared with 13; Tables 1, 2)

(3) more species were present for a greater number of months in that period (21 compared with 15; Tables 1, 2), and

(4) the number of taxa that recorded medium or high abundance ratings was reduced slightly during the second period (eight compared with nine; Figure 4).

Thus, more species appeared and more species showed a greater frequency and occurred for more months during the period of drought than during normal times. This is in accord with Swale (1964) who found that algal populations

TABLE 1

Summary of data on duration of occurrence, frequency and abundance of the common taxa in the Peel River above Chaffey Dam

Taxon	No. months present per 2-year period		Frequency (%)		Abundance*	
	1977–79	1979–81	1977–79	1979–81	1977–79	1979–81
Plankton						
Actinastrum	7	11	8	17	2	1
Anabaina	14	11	26	20	1	0
Ankistrodesmus	7	4	6	4	0	1
Aphanizomenon	4	3	4	7	0	0
Closterium parvulum	16	3	34	5	1	0
C. sp. 1	12	3	26	6	1	0
Cosmarium	6	5	8	5	0	0
Cyclotella	22	19	76	50	24	13
Diatoms	23	24	95	100	21	17
Euglena polymorpha	15	19	28	35	1	3
Gonium	4	7	4	11	0	0
Melosira granulata	5	8	6	10	0	0
M. varians	20	8	33	16	0	0
Pandorina	15	18	21	27	0	0
Pediastrum boryanum	7	10	10	15	1	0
P. duplex	9	16	17	25	0	0
Scenedesmus bijugus	15	14	30	20	2	0
S. obliquus	2	9	2	12	0	0
S. quadricaudus	9	15	10	21	0	0
Schizothrix	9	6	12	8	0	0
Sphaerocystis	9	5	9	9	0	0
Synura	3	10	4	19	0	0
Trachelomonas armata	1	8	1	12	0	1
T. hispida	8	10	13	19	0	0
Attached algae						
Cladophora	19	13	63	27	0	0
Spirogyra	9	8	21	13	0	0

* Number of station-months taxon recorded medium or high abundance ratings.

TABLE 2

Summary of data on duration of occurrence and frequency of rare taxa occurring during both 2-year periods in the Peel River above Chaffey Dam.

Taxon	No. months present per 2-year period		Frequency (%)	
	1977–79	1979–81	1977–79	1979–81
Ceratium	2	3	1	5
Chodatella	1	1	<1	<1
Closterium aciculare	3	1	4	<1
Euglena acus	3	6	2	8
Euglena sp. 2	1	2	<1	4
Microcoleus	1	3	<1	3
Oocystis parva	3	1	3	1
Oscillatoria	3	4	3	5
Peridinium	2	3	2	5
Phacus caudatus	4	5	4	5
Spirulina	1	6	<1	6

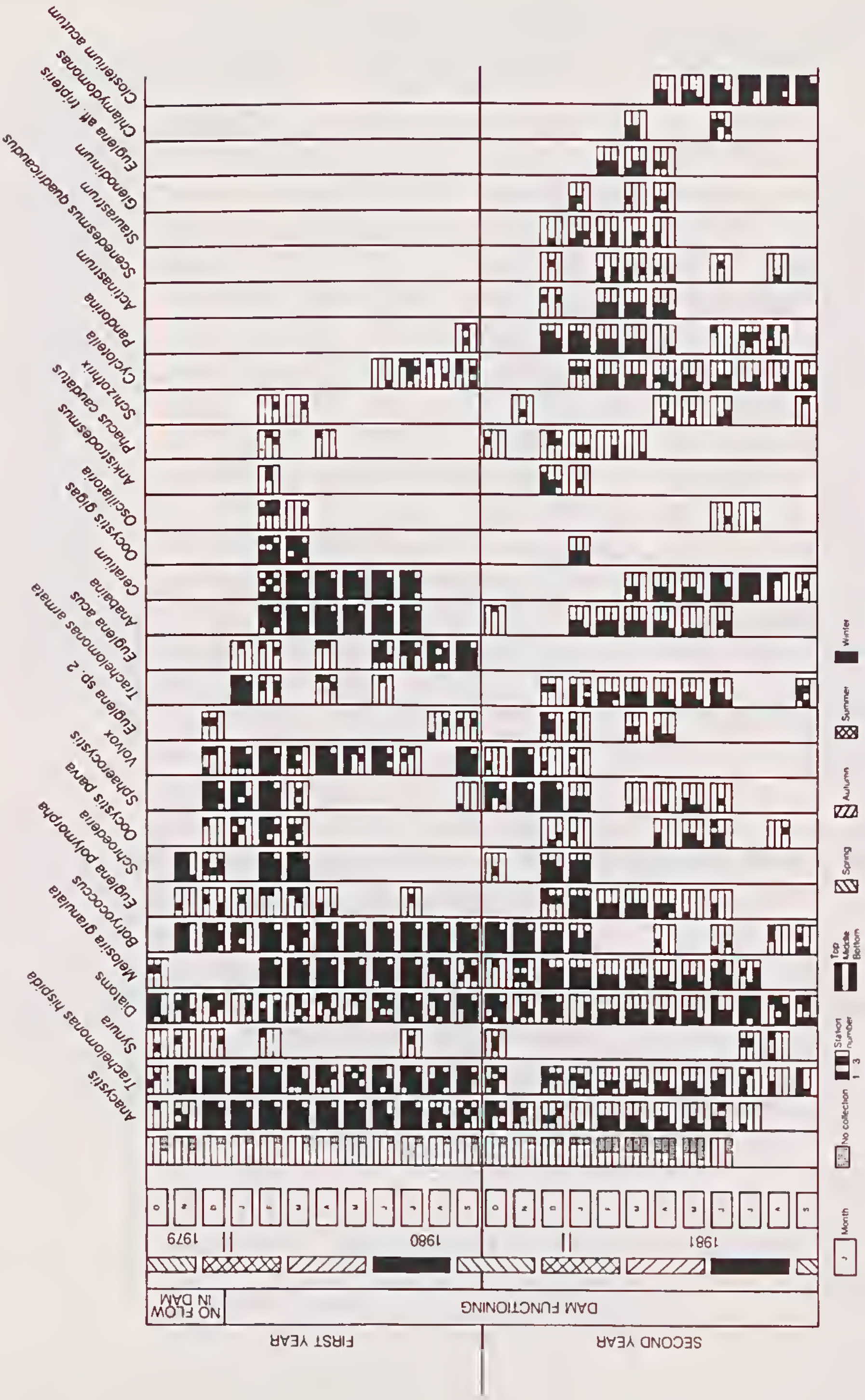

Figure 6. Occurrence of common taxa at different depths at each station in Chaffey Dam. On the left hand side of the diagram the periods of no flow and of the Dam functioning are shown together with the seasons, years, calendar months and times of restricted water sampling.

TABLE 3

Number of taxa present at each station in the Peel River above Chaffey Dam

Station	Number of species	
	1977–79	1979–81
1	19	12
2	30	31
3	27	33
4	29	50
5	29	32
6	26	under dam

were largest in periods of low rainfall. Drought is associated with low water levels, low aeration, and usually with high nutrient levels and such conditions obviously favour certain species. It is noteworthy that some of the taxa listed as associated particularly with the low water levels, namely *Anacystis, Euglena* and *Synura*, are often found in polluted (enriched) water (V. May, pers. observ.).

Distribution of species

Table 3 gives the number of taxa found at each station in each of the 2-year periods. In the first two years, apart from a low reading at station 1 (which is high in the catchment area, has less reliable water-flow, lower nutrient export and is away from the main source area for "seeding" or the introduction of additional species) all stations had a relatively similar number of taxa occurring in them. By contrast, during the second 2-year period, which included the period of drought, the number of taxa at station 1 decreased, while there was an increase at all other stations and particularly at station 4.

Of the 53 species that occurred during the second 2-year period, only three did not occur at station 4, while seven others occurred only at that station. The drainage from the tributaries and from Nundle was sufficient to keep the water level high here despite drought conditions, and the nutrients in this drainage (as indicated by high water conductivity readings: Garman & Townsend, pers. comm.) were sufficient to stimulate the appearance and growth of many species and possibly to extend the occurrence and increase the frequency of others.

Algae of Chaffey Dam

In Figures 6 and 7 the patterns of occurrence of the 48 taxa recorded from Dam stations 1–4 are plotted. In Figure 6 the information for the 30 common taxa is given for all depths of collection at each station, whilst in Figure 7 the data for the 14 rare and four drift species (pieces of formerly attached algae carried down from upstream) are expressed on the basis of station number only. Abundance ratings for the common taxa are shown in Figure 8.

The observations are considered in two equal time periods, from October 1979 to September 1980, when dam conditions were developing, and from October 1980 to September 1981, when conditions were affected by several months of drought. The data on duration of occurrence and on frequency are given in Tables 4 and 5 with abundance data also in Table 4.

Species composition

Twenty-two of the 30 common taxa were present during both 12 month periods, one (*Euglena acus*) was found only during the first 12 months and seven others were restricted to the second 12 months (Figure 6). Various frequency and abundance patterns were shown by these taxa (Table 4, Figure 6). Amongst

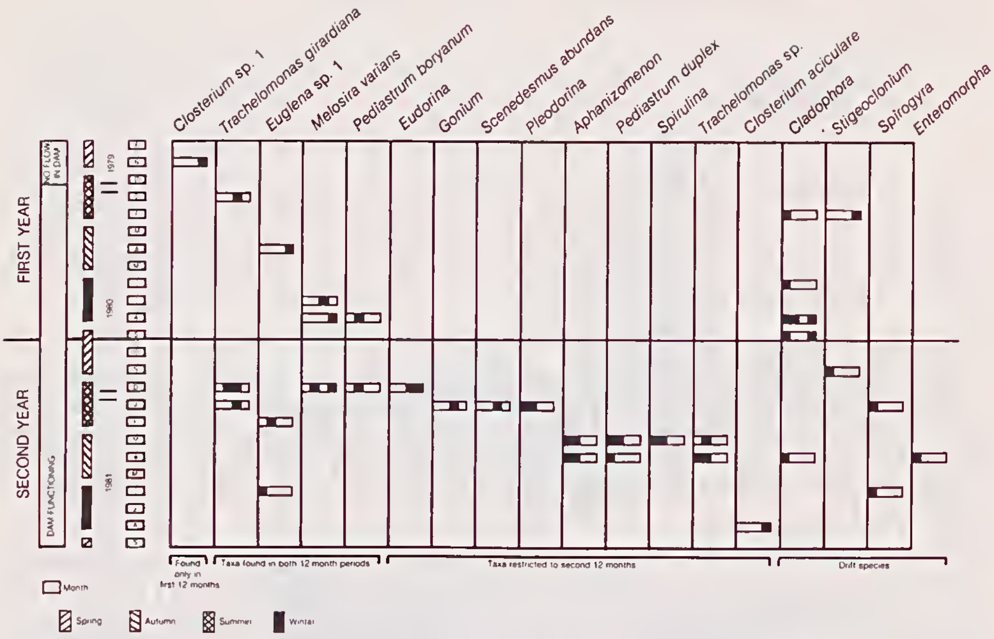

Figure 7. Occurrence of rare and drift species at each station in Chaffey Dam. Data on the left show the period of functioning of the Dam, seasons, years and calendar months.

the 14 rare planktonic taxa, one (*Closterium* sp. 1) was found only during the first 12 months, and 9 were restricted to the second 12 months (Table 5, Figure 7). Of the four species found only as drift material, *Cladophora* was the most common, with *Enteromorpha, Spirogyra* and *Stigeoclonium* being present less frequently (Table 5, Figure 7).

Considering the common and rare species together (omitting drift species):

(1) there was a general increase in the number of taxa recorded over time (Figure 9), with more species being present during the second 12 months than during the first (42 compared with 28). The greatest increase in species numbers occurred in spring and summer.

(2) more species occurred for more months during the second year (30 compared with 10) and showed higher frequencies (33 compared with 11; Tables 4 and 5).

(3) differences in frequency were shown by many of the species over the two 12-month periods. Thus, some taxa were more common during the first 12 months; they showed higher frequencies and were usually present for more months then, while others were more common during the second 12-month period. Some others showed similar frequencies and duration of occurrence in each of the two 12-month periods (Tables 4, 5).

(4) differences in abundance between the two 12-month periods were shown also by some taxa. Of the 17 taxa that were recorded as having medium or high abundance ratings, three were restricted to the first 12 months and a further five were more often abundant then. Six other taxa were restricted to the second 12

TABLE 4

Summary of data on duration of occurrence, frequency and abundance of the common species of Chaffey Dam

Taxon	No. months present per 12-month period		Frequency (%)		Abundance*	
	1979–80	1980–81	1979–80	1980–81	1979–80	1980–81
Plankton						
Actinastrum	—	4	—	18	—	—
Anabaina	6	7	50	31	6	3
Anacystis	12	10	90	56	5	3
Ankistrodesmus	1	2	4	10	—	1
Botryococcus	11	8	92	56	1	2
Ceratium	6	7	50	51	4	3
Chlamydomonas	—	2	—	13	—	1
Closterium acutum	—	6	—	51	—	1
Cyclotella	4	9	19	44	—	2
Diatoms	12	12	94	95	1	2
Euglena acus	7	—	40	—	—	—
Euglena polymorpha	7	7	23	36	—	—
Euglena aff. *tripteris*	—	3	—	13	—	—
Euglena sp. 2	3	4	8	21	—	—
Glenodinium	—	3	—	13	—	—
Melosira granulata	9	10	67	67	3	2
Oocystis gigas	2	1	17	5	—	—
Oocystis parva	4	6	25	28	—	—
Oscillatoria	2	2	6	5	—	—
Pandorina	1	8	4	44	—	3
Phacus caudatus	2	5	6	18	—	—
Scenedesmus quadricaudus	—	6	—	23	—	—
Schizothrix	2	5	4	18	—	—
Schroederia	4	3	29	18	3	2
Sphaerocystis	5	8	31	49	1	2
Staurastrum	—	5	—	23	—	—
Synura	5	3	10	13	—	—
Trachelomonas armata	4	8	19	49	—	1
Trachelomonas hispida	12	11	94	77	2	—
Volvox	8	4	63	18	5	—

* Number of station-months taxon recorded medium or high abundance ratings

months (two of these attained high abundance ratings) and a further three were more often abundant then (Figure 8, Table 4). *Anabaina, Anacystis, Ceratium, Melosira granulata* and *Schroederia* were the taxa most often recorded with medium and high abundance ratings and hence probably contributed most to the biomass in the Dam; such abundance ratings were reached mainly in summer and autumn but occurred also occasionally in winter.

The differences in frequency probably related to a number of factors, including changing water conditions (from flowing to still water) and water depths. The taxa more important during the first 12 months were early colonists and probably tolerant of changing conditions while those more important during the second 12 months may have been favoured by the drought conditions.

The greater algal growth during the second year of the Dam's existence may have resulted from a decrease in water turbidity then or from an increase in "available phosphorus" or from both (Garman & Townsend, pers. comm.).

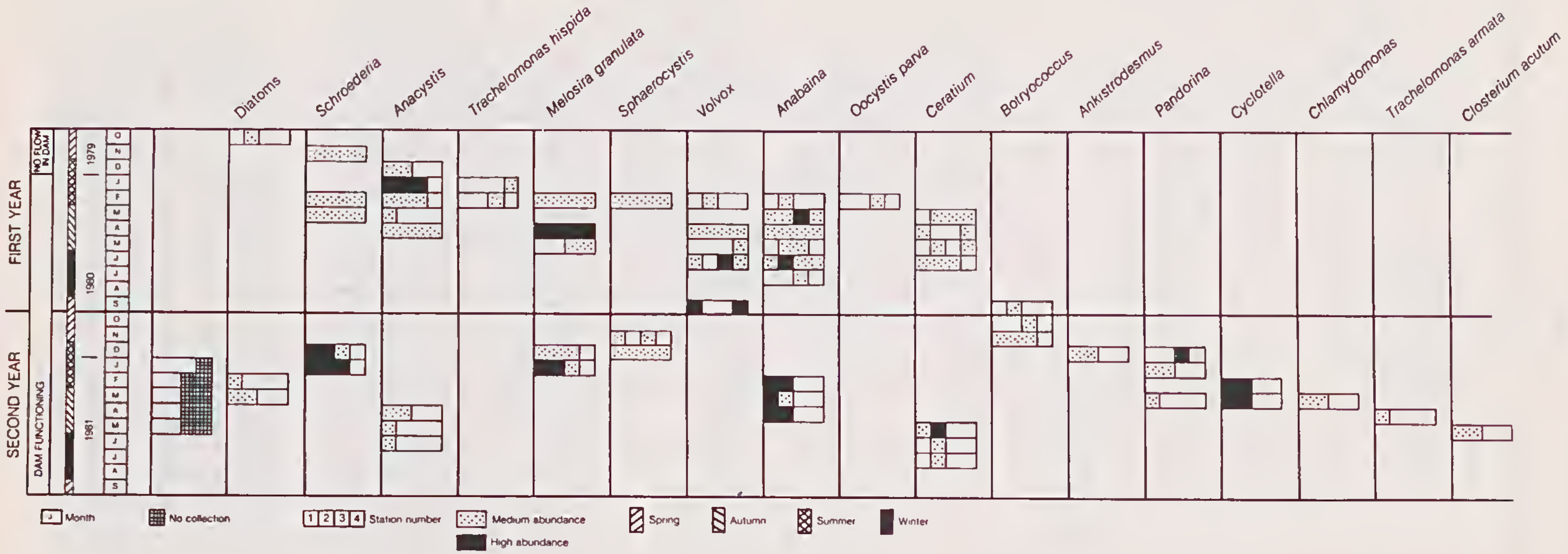

Figure 8. Abundance ratings for taxa at stations in Chaffey Dam. Data on the left show the period of functioning of the Dam, seasons, years, calendar months and times of restricted sampling.

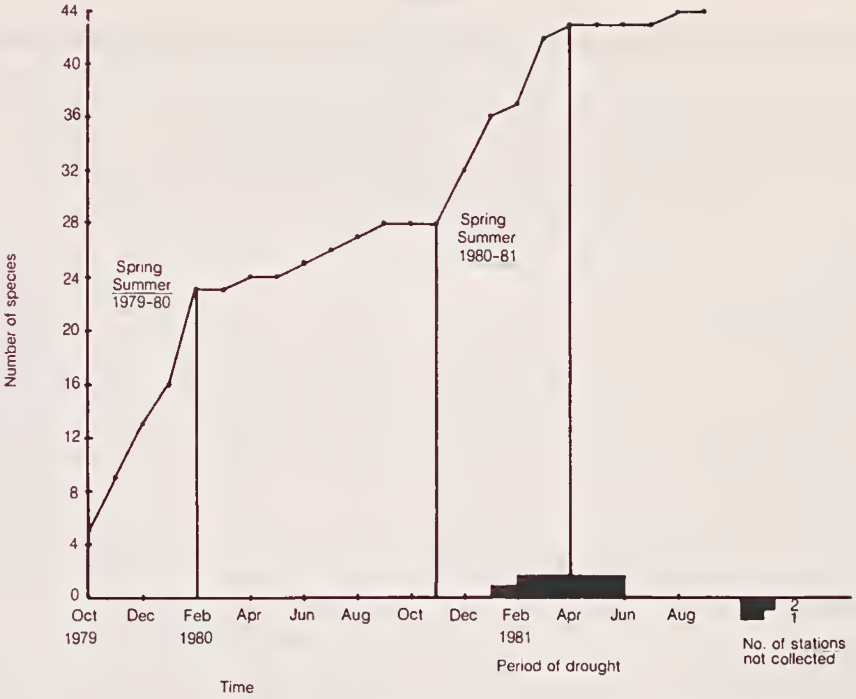

Figure 9. Species-time curve for Chaffey Dam.

Differences between stations

During the first 12-month period, many of the common species were found at all stations within a month or two of their first appearance, suggesting that colonization was more or less concurrent (Figure 6). Some remained more restricted, however, and others, in particular the late summer arrivals were present at only one or two stations. During the second year some species extended their distribution, others changed somewhat, and a number became more restricted (Figure 6). Differences in abundance ratings were not obvious between stations (Figure 8).

Most of the taxa shown in Figure 6 occurred most often at stations 1 and/or 2, the stations that were covered with water first and were least affected by drought conditions. Seven species did not follow this pattern; they occurred equally (*Ankistrodesmus, Phacus caudatus*) or more often (*Euglena acus, E.* sp. 2, *Oscillatoria, Synura, Volvox*) at the upstream stations (3 and 4). The sequence of colonization at station 1 (the oldest, deepest and most stable station, Figures 6 and 7) indicates that these species favour upstream conditions; the taxa listed above (with the exception of *Volvox*) occur late in the sequence and infrequently, if at all, at station 1.

Differences relating to depth of collection

For those taxa with a frequency of over 40 per cent, differences relating to the depths of collections were analysed (Table 6). The majority of the species were surface or near surface dwellers, only *Melosira granulata, Cyclotella* and the "Diatoms" (i.e. other diatom taxa grouped together) being more often at the bottom. *Anabaina, Schroederia* and *Pandorina* appeared to be evenly distributed over the collection depths. Considering differences in abundance (Table 7) a similar pattern was shown, medium and high abundance ratings

TABLE 5

Summary of data on duration of occurrence and frequency of the rare and drift species of Chaffey Dam

Taxon	No. months present per 12-month period		Frequency (%)	
	1979–80	1980–81	1979–80	1980–81
Plankton				
Aphanizomenon	—	2	—	10
Closterium aciculare	—	1	—	3
Closterium sp. 1	1	—	2	—
Eudorina	—	1	—	5
Euglena sp. 1	1	2	2	5
Gonium	—	1	—	3
Melosira varians	2	1	4	5
Pediastrum boryanum	1	1	2	3
Pediastrum duplex	—	2	—	8
Pleodorina	—	1	—	5
Scenedesmus abundans	—	1	—	3
Spirulina	—	1	—	5
Trachelomonas girardiana	1	2	2	8
Trachelomonas sp.	—	2	—	8
Drift species				
Cladophora crispata	4	1	15	3
Enteromorpha	—	1	—	3
Spirogyra	—	2	—	5
Stigeoclonium	1	1	2	3

TABLE 6

Comparison of species presence in top and bottom collections at stations 1 and 2 of Chaffey Dam.*

Taxon	Station 1 No. months present 1979–80		Station 1 No. months present 1980–81		Station 2 No. months present 1979–80		Station 2 No. months present 1980–81		Totals	
	T†	B†	T	B	T	B	T	B	T	B
Anabaina	5	5	5	6	6	6	4	3	20	20
Anacystis	11	9	7	5	10	9	7	1	35	24
Botryococcus	10	7	6	4	11	8	5	5	32	24
Ceratium	6	5	6	3	5	5	6	2	23	15
Closterium acutum	—	—	6	4	—	—	6	2	12	6
Cyclotella	—	2	5	8	—	1	4	6	9	17
Diatoms	7	7	9	10	4	9	7	9	27	35
Euglena polymorpha	1	2	6	3	2	1	5	4	14	10
Melosira granulata	5	7	7	9	7	8	8	6	27	30
Oocystis parva	2	—	3	1	3	—	4	1	12	2
Pandorina	—	—	5	5	—	—	4	4	9	9
Schroederia	3	3	2	2	4	3	2	2	11	10
Sphaerocystis	4	2	6	4	3	3	5	4	18	13
Trachelomonas armata	1	1	6	5	1	2	7	2	15	10
T. hispida	8	8	8	3	12	8	9	2	37	21
Volvox	6	4	1	1	7	4	3	1	17	10

* Only taxa with a frequency of over 40 per cent included.

† T = Top collection; B = Bottom collection.

TABLE 7

Comparison of species abundance in top and bottom collections at stations 1 and 2 of Chaffey Dam

Taxon	No. times recorded medium or high abundance ratings					
	Station 1		Station 2		Totals	
	T*	B*	T	B	T	B
Anabaina	6	5	7	6	13	11
Anacystis	7	1	3	2	10	3
Botryococcus	1	0	2	1	3	1
Ceratium	3	1	4	1	7	2
Closterium acutum	1	1	1	1	2	2
Cyclotella	2	2	2	2	4	4
Diatoms	1	0	0	1	1	1
Melosira granulata	4	2	4	3	8	5
Pandorina	2	0	2	0	4	0
Schroederia	4	1	5	2	9	3
Sphaerocystis	2	0	2	0	4	0
Trachelomonas armata	1	0	0	0	1	0
Volvox	3	0	2	1	5	1

* T = Top collection; B = Bottom collection.

being more often in top collections; equal distribution occurred only with *Cyclotella*, "Diatoms" and *Closterium acutum*.

Results obtained from the thermocline or mid-point collections (Figure 6) were less definite.

Colonization at station 5

In August 1981 rising water levels led to station 5 being covered and nine taxa were recorded then: *Botryococcus, Ceratium, Closterium acutum*, "Diatoms", *Melosira granulata, Trachelomonas hispida, Cyclotella, Pandorina*, and *Spirulina*. In September, *Anabaina* and *Trachelomonas armata* appeared also. The first six of these taxa were amongst the seven most common to be expected in the Dam at any time of the year; only *Anacystis* was absent. Of the other five, three (*Cyclotella, Pandorina, Trachelomonas armata*) occurred in other stations at the same time of year but less commonly.

Cyclotella, Melosira granulata and *Pandorina*, all of which were slow in colonizing the new Dam in the first 12 months (Figure 6) were noted as soon as station 5 became covered with water, and *Closterium acutum* and *Spirulina*, taxa that occurred only in the second year of the Dam's existence (Figures 6 and 7), were present also in August 1981 at station 5. Thus, the presence of water at station 5 appears to have permitted extensions of range of species occurring within the Dam waters at the time, rather than following the pattern of colonization of a new dam.

Algae occurring in the Peel River below the Dam

Species compositions: changes over time-periods 1 to 4

Of the 36 common taxa recorded (Figure 10), 30 were found during the period of Dam construction (period 1: 28 September 1977–20th March 1979). The majority of these appeared in spring and summer 1977–78 (24 taxa), the remainder in later seasons. *Cyclotella* and the other "Diatoms" became abundant on a number of occasions during summer and autumn at all stations during period 1 and five other taxa became abundant at times (Figure 11).

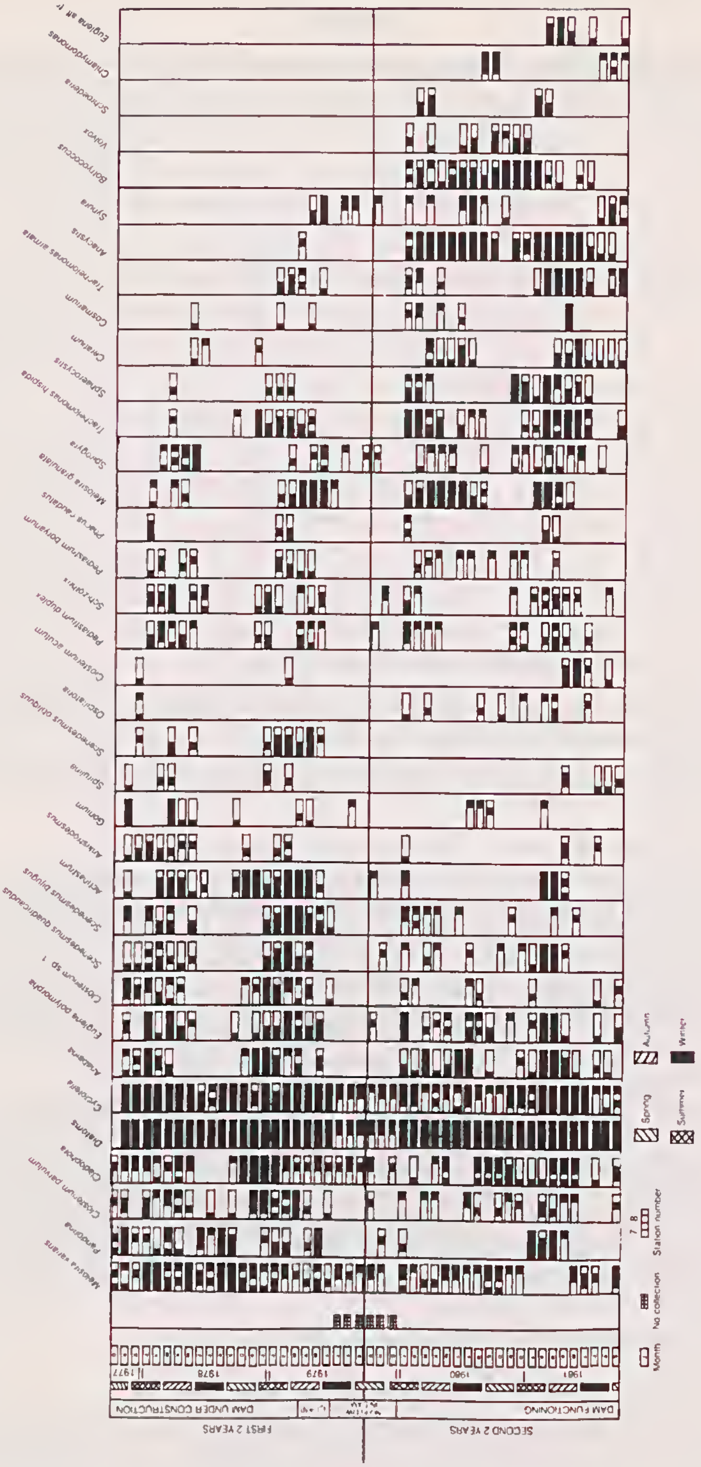

Figure 10. Occurrence of common taxa at stations 7–9 in the Peel River below Chaffey Dam. Data on the left is shown as in Figure 3.

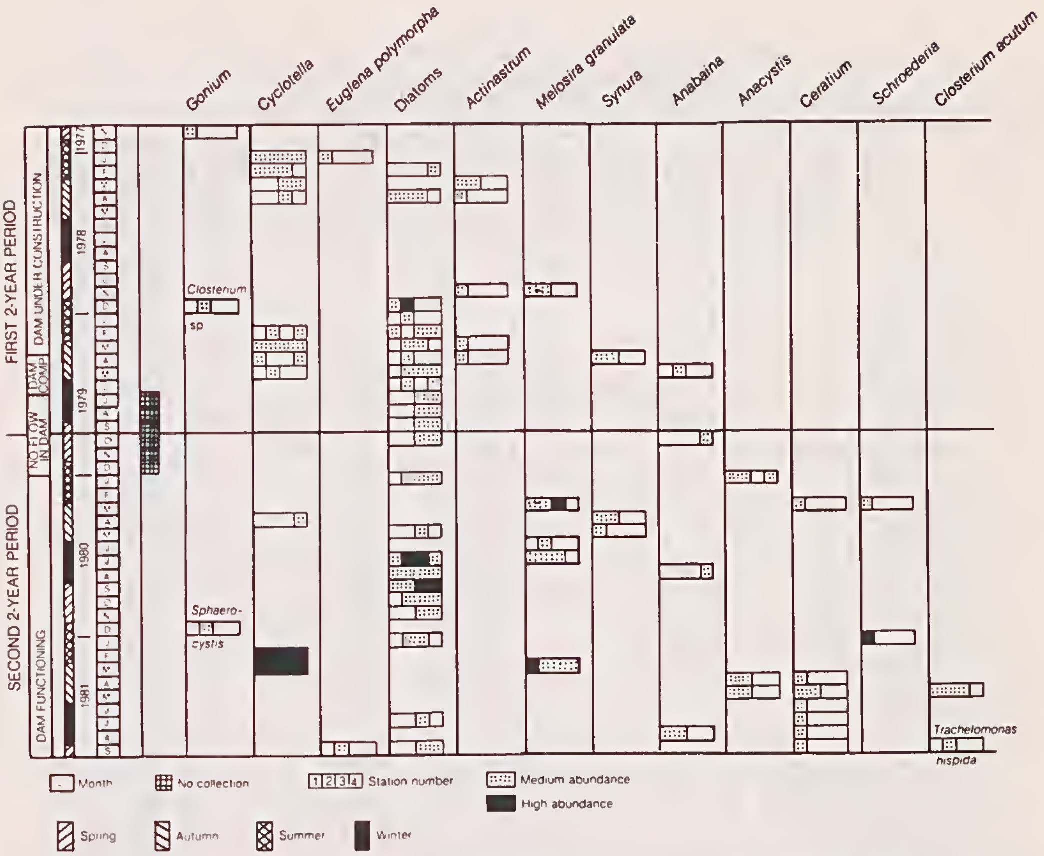

Figure 11. Abundance ratings for taxa at stations in the Peel River below Chaffey Dam. Taxa with only 1 to 2 recordings are plotted together in the first and last columns. Data on the left are shown as in Figure 4.

During period 2 (20th March–26th June 1979, when the Dam was completed) 23 common taxa were recorded. While 10 taxa increased in frequency and one (*Synura*) appeared, the other taxa were either reduced in frequency or were not recorded. Five taxa became abundant on one or more occasions (Table 8, Figure 11).

The number of species recorded was reduced further, to only 14 in period 3 (16th July–11th December 1979), when there was no flow from the Dam. Frequencies were reduced in most cases also, although *Cladophora* and *Melosira varians* increased and the other "Diatoms" remained as before; only two taxa became abundant (Table 8, Figure 11).

During period 4 (after 11th December 1979), when the Dam was functioning, 35 common taxa were recorded. All taxa previously noted, except *Scenedesmus obliquus*, reappeared and five new planktonic algae were recorded. Many of the taxa were present during all seasons and were recorded at all stations at one time or another, but some showed seasonality and/or restricted distributions (Figure 10). Twelve taxa were recorded with medium abundance ratings during period 4 and four of them recorded high ratings once or twice (Figure 11).

Thirty taxa were recorded as rare (Figure 12); 28 of these were algae, the other two being Angiosperms (*Myriophyllum* and *Potamogeton*). Fifteen taxa

TABLE 8

Frequency and abundance of common taxa in the Peel River below Chaffey Dam in each of four periods with differing environmental conditions

	Frequency (%)				Abundance*			
Taxon Period:	1	2	3	4	1	2	3	4
Plankton								
Actinastrum	49	42	8	14	5	1	—	—
Anabaina	39	17	—	42	2	—	—	11
Anacystis	1	—	—	75	—	—	—	7
Ankistrodesmus	21	—	—	5	—	—	—	—
Botryococcus	—	—	—	50	—	—	—	—
Ceratium	4	—	—	25	—	—	—	8
Chlamydomonas	—	—	—	12	—	—	—	—
Closterium acutum	3	—	—	11	—	—	—	3
C. parvulum	39	17	8	18	—	—	—	—
C. sp. 1	35	25	—	8	1	—	—	—
Cosmarium	3	8	—	11	—	—	—	—
Cyclotella	86	100	92	63	16	3	—	9
Diatoms	94	100	100	100	12	6	8	26
Euglena polymorpha	38	42	8	35	1	—	—	1
Euglena aff. *tripteris*	—	—	—	13	—	—	—	—
Gonium	17	8	8	5	1	—	—	—
Melosira granulata	15	75	—	44	—	2	—	3
M. varians	67	42	58	33	—	—	—	—
Oscillatoria	3	—	—	12	—	—	—	—
Pandorina	40	42	8	16	—	—	—	—
Pediastrum boryanum	14	8	—	11	—	—	—	—
P. duplex	22	25	8	19	—	—	—	—
Phacus caudatus	8	—	—	6	—	—	—	—
Scenedesmus bijugus	33	58	—	12	—	—	—	—
S. obliquus	18	42	—	—	—	—	—	—
S. quadricaudus	29	25	8	19	—	—	—	—
Schizothrix	25	25	17	14	—	—	—	—
Schroederia	—	—	—	12	—	—	—	2
Sphaerocystis	6	—	—	31	—	—	—	1
Spirulina	8	—	—	6	—	—	—	—
Synura	—	50	42	19	—	1	1	3
Trachelomonas armata	10	8	—	36	—	—	—	—
T. hispida	22	17	—	48	—	—	—	1
Volvox	—	—	—	16	—	—	—	—
Attached algae								
Cladophora	49	33	58	38	—	—	—	—
Spirogyra	17	33	25	20	—	—	—	—

* Number of station-months taxon recorded medium or high abundance ratings.

occurred in period 1. Five of these taxa were recorded also in period 2 and two additional taxa appeared then, but all except *Trachelomonas girardianum* disappeared by the beginning of period 3. During period 4, 11 of the taxa previously recorded reappeared and 11 additional algae were recorded, together with the two Angiosperms (Figure 12).

Considering the common and rare taxa together, it is clear that great changes in species number occurred during the four periods. The reductions in period 3 seem to be associated with the lower water levels and minimal waterflow, together with seasonal changes, while the increase during period 4 follows the renewed flow of the river, achieved by the intermittent discharge of water from the Dam, which brought further nutrients, oxygen and algae into the downstream area. Garman & Townsend (pers. comm.) report that both

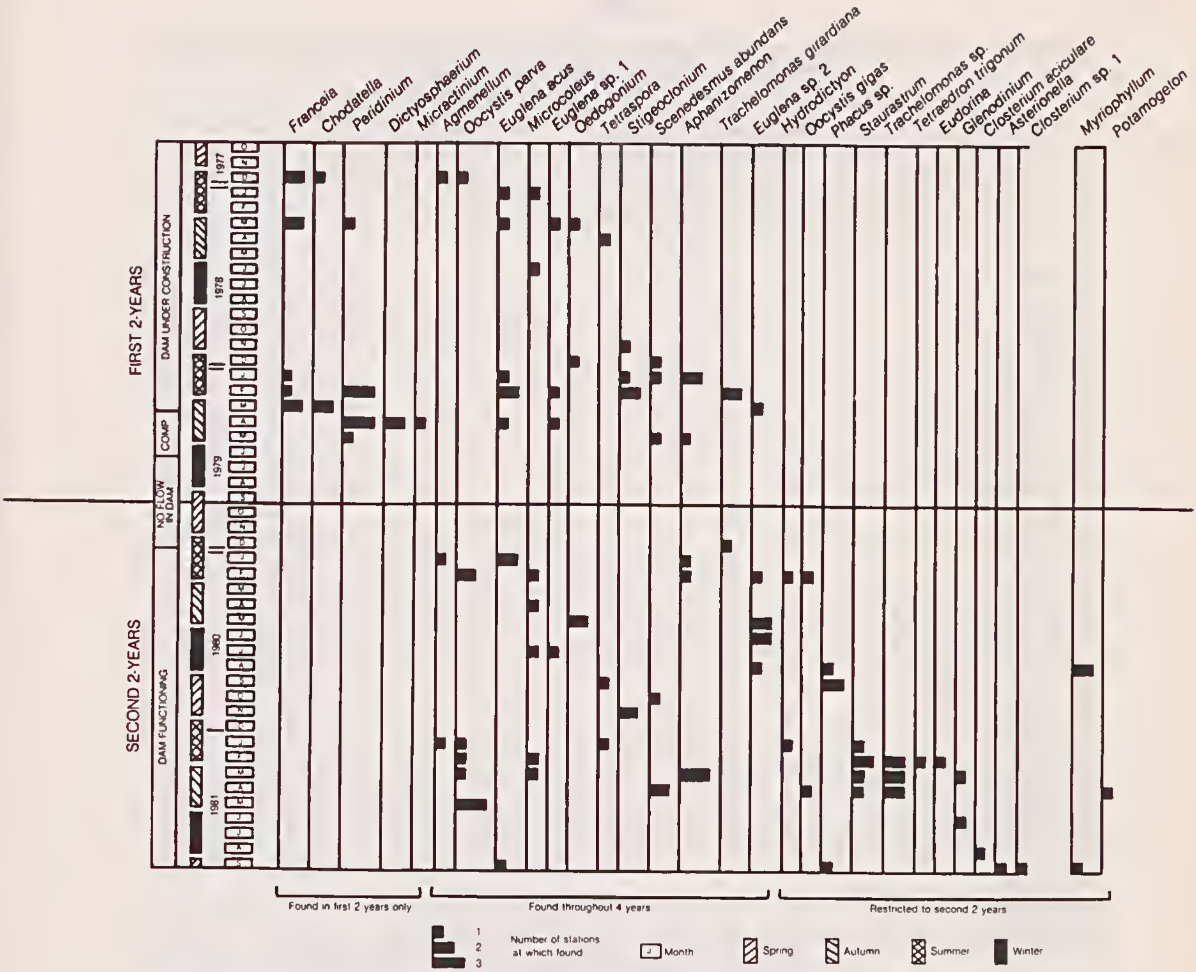

Figure 12. Occurrence of rare algal species and of angiosperms at stations in the Peel River below Chaffey Dam. Data on the left are shown as in Figure 5.

phosphorus and nitrogen were present in significantly higher than normal concentrations at the downstream stations during period 4. Some species are likely to thrive under these enriched conditions. Comparison of the common species in periods 1 and 4 indicate that while *Scenedesmus obliquus* was found only during the first period, six taxa (*Botryococcus, Chlamydomonas, Euglena* aff. *tripteris, Schroederia, Synura* and *Volvox*) occurred only in the fourth period; amongst the rare species, three occurred only in the first period while 11 algae and two angiosperms were found only in the fourth. Some of these taxa were recruited from the Dam waters, but it seems likely that the increased numbers of taxa in Period 4 were also a response to particularly high nutrient levels.

Comparison of the two 2-year periods

The data for the common species for the two 2-year periods (Table 9) indicate that there were a greater number of taxa present during the second 2-year period (35 compared with 31), and that more taxa were present for a greater number of months during the second period compared with the first (22 compared with 12). Also, more taxa were recorded as abundant during the second period (12 taxa compared with 9).

TABLE 9

Summary of data on duration of occurrence, frequency, abundance and seasonality of the common taxa in the Peel River below Chaffey Dam

Taxon	No. months present per 2-year period		Frequency and abundance*		Seasons present†	
	1977–79	1979–81	1977–79	1979–81	1977–79	1979–81
Plankton						
Actinastrum	15	5	44 (6)	14	All	Sp, S, A
Anabaina	12	16	33 (2)	39 (11)	Sp, S, A	All
Anacystis	1	19	1	70 (7)	A	All
Ankistrodesmus	10	3	17	4	Sp, S, A	S, A, W
Botryococcus	—	17	—	47	—	All
Ceratium	3	12	3	23 (8)	A, W, Sp	A, W, Sp
Chlamydomonas	—	5	—	11	—	W, Sp
Closterium acutum	2	4	2	10 (3)	S	A, W
C. parvulum	16	14	33	18	All	All
C. sp. 1	14	7	31 (1)	8	All	S, W
Cosmarium	3	5	3	10	S, A	All
Cyclotella	23	24	89 (19)	64 (9)	All	All
Diatoms	23	24	96 (24)	100 (28)	All	All
Euglena polymorpha	14	15	36 (1)	33 (1)	Sp, S, A	All
Euglena aff. *tripteris*	—	5	—	12	—	All
Gonium	7	5	16 (1)	4	Sp, A, W	Sp, S, W
Melosira granulata	9	12	22 (2)	41 (3)	S, A, W	S, A, W
M. varians	24	18	63	34	All	All
Oscillatoria	1	8	1	11	S	All
Pandorina	16	6	38	16	All	Sp, S, A
Pediastrum boryanum	8	9	12	10	S, A	All
P. duplex	10	11	21	19	Sp, S, A	All
Phacus caudatus	3	3	7	6	S	S, A
Scenedesmus bijugus	12	8	34	11	All	All
S. obliquus	9	—	21	—	S, A	—
S. quadricaudus	13	11	27	19	Sp, S, A	All
Schizothrix	11	10	23	16	All	All
Schroederia	—	4	—	11 (2)	—	S, A
Sphaerocystis	4	11	4	29 (1)	S, A	All
Spirulina	5	4	7	6	Sp, S, A	A, W, Sp
Synura	4	10	7 (1)	18 (4)	A, W	All
Trachelomonas armata	4	11	9	33	S, A	All
T. hispida	8	15	20	44 (1)	Sp, S, A	All
Volvox	—	8	—	14	—	All
Attached algae						
Cladophora	21	17	48	39	All	All
Spirogyra	9	14	20	20	All	All

* Figures in brackets give number of station-months taxon recorded medium or high abundance ratings.

† Sp = spring; S = summer; A = autumn; W = winter; All = all year.

A similar pattern was shown by the rare taxa with regard to species number. However, changes in the duration of occurrence amongst the taxa found during both periods were not marked (Table 10).

Distribution of species

During the period of Dam construction (period 1), more species were recorded at station 7 than at other stations downstream from the Dam work-site (Table 11). During Period 2 the same pattern of distribution was shown, but once the Dam became functional (period 4), a relatively similar number of

TABLE 10

Summary of data on duration of occurrence and frequency of rare taxa occurring during both 2-year periods in the Peel River below Chaffey Dam

Taxon	No. of months present per 2-year period		Frequency (%)	
	1977–79*	1979–81†	1977–79*	1979–81†
Plankton				
Agmenellum	1	2	1	2
Aphanizomenon	2	3	3	6
Euglena acus	5	2	7	3
E. sp. 1	3	1	3	1
E. sp. 2	1	4	1	7
Microcoleus	2	5	2	6
Oedogonium	2	1	2	2
Oocystis parva	1	5	1	9
Scenedesmus abundans	3	2	3	3
Tetraspora	1	2	1	2
Trachelomonas girardiana	1	1	2	1
Attached alga				
Stigeoclonium	3	1	4	2

* Includes periods 1, 2 and half of 3; † includes second half of period 3 and period 4.

species was found at each station. The higher species richness of station 7 compared with the other stations during the first two periods was probably related to the effect of increased nutrients (as shown by high conductivity readings; Garman & Townsend, pers. comm.), which became available following soil disturbance at the work-site.

Taxa with medium abundance ratings were recorded more often at stations 7 and 7A than at stations 8 and 9, but high abundance ratings were more or less equally spread between stations (Table 11, Figure 11).

TABLE 11

Number of species present and recording medium or high abundance rating at stations 7–9 during periods 1 to 4 and over each two years

Station	Period								Two-year period			
	1		2		3		4		1977–79		1979–81	
	No.	Ab.	No.	Ab.	No.	Ab.	No.	Ab.	No.	Ab.	No.	Ab.
7	39	6	26	3	—	—	41	9	42	7	41	9
7A	31	5	19	4	—	—	46	10	35	6	46	10
8	33	2	16	1	11	1	42*	4	34	2	43*	4
9	26	2	13	2	9	2	43†	4	28	2	43	4

* Plus two angiosperms; † plus one angiosperm.
No. = number of species present; Ab. = Abundance (i.e., number of taxa recording medium or high abundance ratings).

DISCUSSION

Comparison of taxa at upstream stations (1–6) and downstream stations (7–9)

Of the 71 taxa recorded at the various river stations during the study, 52 were present at both sets of stations at some time or another. Comparison of the data from the two sets of river stations for the two 2-year periods indicates a wide range of distribution and occurrence patterns, with some taxa found as common, others as rare at both sets of stations during both time-periods (Figures 3, 5, 10, 12), while others were noted as rare at the upstream stations, common downstream, or showed the reverse pattern.

Five species were restricted to the upstream stations: *Diacanthos, Dinobryon, Enteromorpha, Tetraedron limniticum* and *T. regulare;* they were found only during the second two years and then only rarely. Fourteen species were restricted to the downstream stations. Of these, two were found rarely during the first two years (*Dictyosphaerium, Micratinium*), two were rarely present during both periods (*Agmenellum, Tetraspora*) and ten others were found only during the second two years.

Comparison of the data on number of species, duration of occurrence and seasonality of individual species indicate that similar trends were shown by both sets of stations. Thus, at both the upstream and downstream stations there was an increase in the number of taxa present during the second 2-year period (which included the period of drought), and this was particularly so in the downstream stations; and more species were present for a greater number of months then. Also, some species showed extensions to the range of seasons during which they were recorded in the second two years. On the other hand, comparisons of frequency and abundance ratings indicate differences between the two sets of stations. At the upstream stations more species showed higher frequencies during the second 2-year period but the number of taxa becoming abundant during the second two years was reduced slightly compared with the first two years, while at the downstream stations, the number of species showing increased frequencies during the second 2-year period did not increase, but more taxa became abundant then. It is suggested that overflow from the Dam acted to increase the abundance of some of the common species there.

Effect of changing water levels and water flow conditions on various species

Comparison of the data on duration of occurrence and on frequency for the common species at the two sets of river stations indicate that some species were present more often and for longer periods during normal conditions (*Ankistrodesmus, Cladophora, Closterium parvulum, C.* sp. *1, Cyclotella, Melosira varians, Scenedesmus bijugus* and *Schizothrix*), whilst others were favoured by drought conditions (*Melosira granulata, Synura, Trachelomonas armata, T. hispida*; also *Ceratium* and *Oscillatoria* (rare at upstream stations but common at stations 7–9)). The data for the other common species differed from one set of stations to the other, for example, *Actinastrum, Gonium, Pandorina, Scenedesmus obliquus* and *S. quadricaudus* all showed increased frequencies and duration of occurrence during the second 2-year period at the upstream stations, but decreased or disappeared at downstream stations 7–9. The opposite trend was shown by *Anabaina.* Comparisons for the rare species are not considered meaningful.

Comparison of species within Chaffey Dam with those at the upstream and downstream river stations

Forty-three species were found in both the Dam and the stations in the river upstream of the Dam. Of these, 14 were common in both places, while eight others were rare in both places. It seems likely that the appearance of the species in the Dam resulted from transfer from the upstream stations with subsequent development as the Dam filled. Some of the common species at the upstream stations (*Closterium parvulum, Cosmarium, Scenedesmus bijugus, S. obliquus*) and a number of the rare species (*Chodatella, Diacanthos, Dinobryon, Franceia, Microcoleus, Oedogonium* and *Peridinium*) were not recorded in the Dam. It seems that these taxa did not survive under Dam conditions, or were never transferred to the Dam.

Five other taxa were found in the Dam but not in the upstream stations (*Botryococcus, Eudorina, Oocystis gigas, Pleodorina* and *Volvox*); these appear to have been recruited from outside the section of the Peel River studied.

Forty-six species were found in both the Dam and the downstream stations. Of these, 24 were common in both areas at various times and another eight were rare in both places; the remaining taxa showed various patterns of distribution and frequency categories (Tables 4, 5 compared with 9, 10). Four of the five species recorded as present in the Dam, but not at the upstream stations, were recorded at the downstream stations: *Botryococcus* and *Volvox* were common in both areas, *Eudorina* rare in both and *Oocystis gigas* common in the Dam but rare at the downstream, stations. It seems that water discharged from the Dam at various times permitted the transfer of these taxa to the stations downstream.

Lacustrine and fluvial species

Some 13 taxa, rare at the upstream river stations became common in the Dam (*Anacystis, Ceratium, Euglena acus, E.*sp. 2, *Oocystis parva, Oscillatoria, Phacus caudatus, Schroederia* and the later entrants, *Chlamydomonas, Closterium acutum, Glenodinium, Euglena* aff. *tripteris* and *Staurastrum*); it appears that these taxa were favoured by Dam habitat conditions (more stable waters and temperatures than in the river) and they may be assigned tentatively to a "lacustrine species" category. Some, such as *Euglena acus, E.* sp. *2, Glenodinium, Oocystis parva* and *Staurastrum,* were rare also at the downstream stations, but the others listed above were noted as common at the downstream stations. Water discharge from the Dam may have affected the frequency ratings of these taxa, or other factors, such as water temperatures or nutrient availability, may have been involved.

Eight other taxa, common at the upstream river stations become rare in the Dam; included here were *Closterium* sp. 1, *Melosira varians, Pediastrum boryanum, Cladophora* and *Spirogyra*, and the later arrivals in the Dam, *Aphanizomenon, Gonium* and *Pediastrum duplex.* These species were common also in the downstream river stations (except for *Aphanizomenon* which was rare there); together with others recorded as present only within both areas of the river (*Chodatella, Closterium parvulum, Cosmarium, Franceia, Microcoleus, Oedogonium, Peridinium, Scenedesmus bijugus, S. obliquus* and *Tetraedron trigonum*) or restricted to one part of the river or the other (as discussed previously). They appear to be favoured by river habitat conditions, and can be assigned tentatively to the "fluvial species" category.

Pleodorina was the only species noted as restricted wholly to the Dam itself. These results contrast strongly with those of Aykulu (1982) who states "it is rare to find lake plankton species in the river plankton". The difference could well be due to the short history of the Chaffey Dam. At least some differences are beginning to become apparent, as discussed above, and these may become more defined in later years.

Abundance ratings

Comparison of these data for the comparable 2-year period (1979–81) indicate that more species became abundant within the Dam than outside of it (17 taxa compared with eight at upstream river stations and 12 at downstream river stations) and also more species recorded high abundance ratings within the Dam (eight taxa compared with two at the upstream stations and four at the downstream stations). Contrasting with this, however, were the two most frequently present taxa in this area, *Cyclotella* and the other "Diatoms"; both recorded medium abundance ratings less often and the latter also high abundance ratings less often within the Dam compared with the outside river stations. Three other taxa, *Actinastrum, Euglena polymorpha* and *Peridinium* became abundant at one or both sets of river stations only (Figures 4, 8, 11).

Influence of dam waters on downstream stations

The possible influence of discharged Dam waters on the stations downstream has already been mentioned in relation to the composition of the floras and the changes in frequency for individual species. Further support for the suggestion comes from the abundance ratings. A number of the taxa that recorded medium and/or high abundance ratings within the Dam also became abundant at the downstream stations but did not do so at the upstream stations. The difference was particularly marked with *Anabaina* and *Ceratium.* It seems likely that these taxa were carried with the discharged dam water, surviving and developing further at the downstream stations.

The attached species

There were a number of larger plants that occurred in the river from time to time growing attached to the substrate. The most recurrent of these was *Cladophora,* and *Spirogyra* was also commonly present.

Active growth of *Cladophora* usually started between August and November and continued until May or June, but at times it persisted all through the year. Specimens varied greatly in the frequency of branching, cell width and degree of infestation of diatoms, but this was not directly seasonal. Both old plants bearing epiphytes and young actively branching plants could be obtained together at times. Generally, however, associated (epiphytic or entangled) species, mainly diatoms, became more frequent between January and May.

Occurrences of *Cladophora* at stations 7 and 7A were very low compared with those at other stations in the river during 1977–79 (Figures 3, 10); the attached alga may have been adversely effected by the presence of sediment in the water, caused by the construction of the Dam. *Cladophora* thrived everywhere in the absence of drought. This result is surprising since Williams (1978) reports that *Cladophora* is favoured by the presence of high mineral, particularly phosphate, levels, such as likely to obtain during droughts. Whitton (1970) on the other hand, has pointed out that *Cladophora* tends to be more prolific where there is maximum water movement and aeration. However, very strong increases in waterflow can cause the disappearance of the alga, for example, after heavy rain in May 1978 there was no attached *Cladophora* at any station until the following August.

The growth of *Spirogyra* contrasts somewhat with this. It was seasonal at stations 1–5, but was found throughout the year at stations 7–9. It did not seem to be adversely affected by the drought conditions, or by other factors such as sediment loads in the water. Occurrences at all stations varied throughout the study period, but were not markedly more or less at stations 7 and 7A than elsewhere. At stations 7–9, *Spirogyra* was recorded for more months during the second 2-year period, with frequencies nearly the same during both periods. At the upstream river stations duration of occurrence was equal during the two time periods while frequencies were reduced somewhat during the second two years.

The other attached species, namely *Enteromorpha, Hydrodictyon, Oedogonium* and *Stigeoclonium* amongst the algae, and *Myriophyllum* and *Potamogeton* amongst the macrophytes, were only of rare occurrence anywhere in the Peel River area studied.

CONCLUSIONS

1. Seventy-two taxa were recorded: 64 planktonic algae, six attached algae and two aquatic angiosperms. While some taxa were restricted to river areas (24), to the Dam (1) or were found in the Dam and in one part or another of the River (5), most were present in all areas (42 taxa).

2. Changes in the presence of individual taxa and in their frequency, abundance, duration of occurrence and seasonality were related to changes in water flow, to differences in water depth and temperature, and in the availability of nutrients. Successional changes may have contributed to some changes within the Dam.

3. In all areas an increase in the number of species and increases in frequency and duration of occurrence of some taxa were associated with times of drought. Some taxa, however, flourished more during periods of normal water flow.

4. In downstream areas increased nutrient availability associated with soil disturbance during the construction of the Dam resulted in a temporary increase in the number of taxa occurring at the station immediately below the Dam wall.

5. Colonization was more or less concurrent at the Dam stations with algae derived mainly from upstream, but some from outside this region. There was a general increase in species number over time. Most taxa in the Dam flourished at or near the surface rather than at lower depths.

6. Discharged or overflowing water from the Dam influenced to some extent the composition and characteristics of the flora at downstream stations. More species were recorded as abundant there and in the Dam than at the upstream river stations.

7. Some taxa appeared to be favoured by the habitat conditions of the Dam, while others were restricted to the River or were favoured more by river conditions. They can be assigned tentatively to "lacustrine species" and "fluvial species" categories respectively.

Present knowledge of the physiological requirements of individual algal species is incomplete, but detailed records of changes in the occurrence, frequency, abundance and seasonality of indivdual species under differing conditions, such as given here, are a pre-requisite for the proper use of these organisms in biological surveillance. It should be emphasized, however, that there are profound differences in the flow regimes of rivers in Australia compared with those in many other parts of the world and hence some of the results obtained within Australia may not be applicable elsewhere.

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APPENDIX 1

Species recorded from the Peel River and Chaffey Dam

Actinastrum hantzschii Lag.
Agmenellum thermale (Kuetz.) Drouet & Daily
Anabaena circinalis Rabenh.
Anacystis cyanea (Kuetz.) Drouet & Daily (*Microcystis aeruginosa* Kuetz.)
Ankistrodesmus falcatus (Corda) Ralfs
Aphanizomenon (ecophene of *Calothrix parietina* (Naeg.) Thuret)
Asterionella sp.
Botryococcus braunii Kuetz.
Ceratium hirundinella (O. F. Muell.) Dujardin
Chlamydomonas sp.
Chodatella subsalsa Lemm. (*Lagerheimia*)
Cladophora crispata (Roth) Kuetz.
Closterium aciculare T. West
C. acutum (Lyngb.) de Bréb.
C. parvulum Naeg.
C. sp. 1
C. sp. 2
Cosmarium sp.
Cyclotella meneghiniana Kuetz.
Diacanthos belenophorus Koreh.
Diatoms (undetermined species)
Dictyosphaerium pulchellum Wood
Dinobryon sertularia Ehrenb.
Enteromorpha sp.
Eudorina elegans Ehrenb.
Euglena acus Enrenb.
E. polymorpha Dang.
E. aff. *tripteris* (Dujardin) Klebs
E. sp. 1
E. sp. 2
Franceia droescheri (Lemm.) G. M. Smith
Glenodinium sp.
Gonium pectorale Muell.
Hydrodictyon reticulatum (L.) Lag.
Melosira granulata (Ehrenb.) Ralfs
M. varians Ag.
Micractinium pusillum Fres.
Microcoleus lyngbyaceus (Kuetz.) Crouan
**Myriophyllum* sp.
Oedogonium sp.
Oocystis gigas Archer
O. parva West & West
Oscillatoria ? lutea Ag.
Pandorina morum (Muell.) Bory
Pediastrum boryanum (Turp.) Meneghini
P. duplex Meyen
Peridinium granulosum P'fair
Phacus caudatus Huebner
P. sp.
Pleodorina sp.
**Potamogeton ochreatus* Raoul
Scenedesmus abundans (Kirchner) Chodat
S. bijugus (Turp.) Kuetz.
S. obliquus (Turp.) Kuetz.
S. quadricauda (Turp.) de Bréb.
Schizothrix calcicola (Ag.) Gomont
†*Schroederia judayi* G. M. Smith
Sphaerocystis schroeteri Chodat
Spirogyra sp.
Spirulina subsalsa Oersted
Staurastrum pingue Teiling
Stigeoclonium sp.
Synura adamsii G. M. Smith
Tetraëdron limniticum Borge
T. regulare Kuetz.
T. trigonum (Naeg.) Hansgirg
Tetraspora lubrica (Roth) Ag.
Trachelomonas armata (Ehrenb.) Stein
T. girardiana (P'fair) Deflandre
T. hispida (Perty) Stein
T. sp.
Volvox globator L.

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* Angiosperms

† There is some current concern about the identity of this species. Although our material appears to match the description and illustrations of the species named, neither the senior author nor Mr I. Smalls (per. comm., New South Wales Metropolitan Water Drainage and Sewerage Board) have ever seen flagellate zoospores, as might be expected in *Schroederia*.

APPENDIX 2

The Diatom Flora of the Peel River and Chaffey Dam, New South Wales

by

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A study was made of the diatom flora of the Peel River from January, 1978 to August, 1981 and of that of the Chaffey Dam from April, 1980 to February, 1983. Because of drought the collections were not continuous and no conclusions could be drawn about the effect of the dam on the diatom population of the river.

Collections were made as described in the main paper. Species recorded each date could include planktonic species, epiphytes and diatoms caught in attached plants (the latter largely absent in the Dam study).

Of the numerous diatom species found in the river, 34 taxa which appeared fairly regularly or were distinctive, were selected for more detailed study. Increasing density of a taxon was recorded ranging from rare, low, moderate, frequent to dominant. If the total number of diatoms present on any one slide was above 100–200 then the chosen taxon was recorded as a percentage of the total diatom population of the sample. This percentage basis for recording was then adopted because of the vast variation in the total diatom concentration in the various samples.

The accompanying table gives a summary of the information obtained for eight of the most prevalent taxa using the following symbols to denote the concentration—

O = No samples available.
X = No specimens in sample.
R = Rare—less than 1 per cent.
L = Low—1–10 per cent.
M = Moderate—10–30 per cent.
F = Frequent—more than 30 per cent.
* = Dominant taxon in sample.

It should be noted that only occasional samples from Stations 7 and 7A were available for the period June, 1978 to November, 1979 and that few diatoms appeared there during this period, possibly owing to the absence of *Cladophora* during most of this time. The presence of large quantities of suspended clay in the water resulting from the construction of the Dam may also have affected the populations.

In addition to the taxa listed in the tables the following were also recorded—

Achnanthes lanceolata Breb. ex Kütz.
Amphora spp.
Anomoeoneis spp.
Cymatopleura spp.
Cymbella spp.
Epithemia spp.
Eunotia spp.
Fragilaria spp.
Frustulia spp.
Hantzschia amphioxys (Ehr.) Grun.
Melosira varians Ag.
Meridion circulare (Grev.) Ag.
Pinnularia spp.
Pleurosigma/Gyrosigma spp.
Rhopalodia spp.
Surirella spp.

The information obtained from the river is more complete than that from the Dam, since samples taken from a large body of water, well out from the shore, do not contain a very large number of diatoms unless there is a particularly heavy bloom of them present.

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Station No.	Year/Quarter																				
	1978				1979				1980				1981				1982				1983
	D/F	M/M	J/A	S/N	D/F	M/M	J/A	S/N	D/F	M/M	J/A	S/N	D/F	M/M	J/A	S/N	D/F	M/M	J/A	S/N	D/F
Cocconeis placentula Ehr.																					
Peel River																					
1.	F*	M	O	M	F*	F*	F	F*	F*	O	M*	L	O	M*	L						
2.	F*	F*	O	M	F*	F*	M*	F*	F*	O	R	L	O	L	L						
3.	L	L	O	M	F*	L	L	M	F*	O	L	L	O	R	R						
4.	F*	L	O	M*	F*	F*	L	M	F*	L	M	L	L	L	L						
5.	M	F*	O	M	F*	M*	L	F*	F*	L	L	M*	O	R	R						
7.	O	R	O	O	O	O	O	O	R	L	L	L	M	L	L						
7A.	O	R	O	O	O	O	O	O	R	L	M	L	R	M	M						
8.	L	M	O	M*	F*	L	M*	M	M	M	M*	L	M	M*	L						
9.	L	M	O	M	F*	L	L	M	M	M*	M*	L	M*	M*	L						
Chaffey Dam																					
1.										X	R	R	R	R	R	R	R	R	X	R	R
2.										X	X	X	X	R	R	R	X	R	R	X	R
3.										X	R	R	X	O	R	R	R	R	R	R	X
4.										R	R	R	R	O	R	L	R	R	X	X	O
5.										O	O	O	O	O	O	R	O	O	O	O	O
Cyclotella spp. (predominantly *C. meneghiniana* Kütz. with some *C. stelligera* Cleve & Grun.)																					
Peel River																					
1.	R	R	O	X	X	R	X	X	R	O	R	X	R	R	X						
2.	R	L	O	X	R	R	X	X	R	R	M*	R	R	R	X						
3.	R	L	O	X	X	L	R	X	M*	R	L	R	R	R	R						
4.	R	M*	O	X	X	L	X	X	M*	M*	M*	L	M*	L	R						
5.	R	L	O	X	X	L	R	X	M*	M*	L	L	O	M*	R						
7.	O	R	O	O	O	O	O	O	R	X	R	X	L	F*	M*						
7A.	O	R	O	O	O	O	O	O	L	X	X	L	M*	F*	L						
8.	R	L	O	X	X	R	L	R	L	R	R	R	M*	F*	R						
9.	R	L	O	X	X	M	R	X	L	L	L	L	L	F*	L						

Chaffey Dam																					
1.										X	R	R	M*	F*	F*	F*	L	F*	F*	F*	F*
2.										X	R	X	M*	F*	F*	F*	L	F*	F*	M*	M*
3.										X	R	R	X	O	F*	F*	L	F*	R	M*	M*
4.										X	R	X	R	O	F*	M*	L	F*	R	L	R
5.										O	O	O	O	O	M*	F*	R	O	O	O	O
Gomphonema spp. (including *G. accuminatum* Ehr. var. *coronata* (Ehr.) Kütz., *G. clevei* Fricke, *G. constrictum* Ehr., *G. gracile* Ehr. and *G. parvulum* (Kütz.) Grun.)																					
Peel River																					
1.	M	F	O	F*	M	M	L	F*	M	O	M	M	O	F*	M						
2.	M	M	O	M	M	M	L	F*	L	O	F*	F*	O	O	M						
3.	M	M	O	F*	L	L	M	F*	L	O	M	M*	O	L	L						
4.	M*	M	O	F*	L	L	L	F*	L	M	M	F*	M	L	L						
5.	L	M	O	M	L	L	L	F*	L	L	M	M	O	O	M						
7.	O	O	O	O	O	O	O	O	M	L	M	F*	F*	M	M*						
7A.	O	L	O	O	O	O	O	O	L	L	L	F*	L	L	M						
8.	L	L	O	F*	L	L	M	F*	M*	L	M	M	F*	L	L						
9.	M	L	O	F*	M	L	L	F*	M*	L	L	L	M	L	L						
Chaffey Dam																					
1.										R	R	L	R	R	R	R	R	R	R	L	R
2.										X	R	X	L	R	R	R	R	R	X	L	R
3.										R	R	L	R	O	R	R	R	R	R	R	R
4.										L	R	R	R	O	R	R	R	R	R	L	O
5.										O	O	O	O	O	R	R	R	O	O	O	O
Melosira granulata (Ehr.) Ralfs																					
Peel River																					
1.	X	X	X	X	X	R	X	X	X	X	X	X	R	R	X						
2.	X	R	O	R	L	R	X	X	X	O	R	R	O	O	X						
3.	X	X	O	X	X	R	X	X	X	O	X	X	O	O	X						
4.	X	X	O	X	R	R	X	X	X	X	R	X	R	L	X						
5.	X	X	O	X	X	M*	X	X	X	O	X	R	O	O	R						
7.	O	O	O	O	O	O	O	O	R	F*	L	L	L	L	R						

Station No.	Year/Quarter																				
	1978				1979				1980				1981				1982				1983
	D/F	M/M	J/A	S/N	D/F	M/M	J/A	S/N	D/F	M/M	J/A	S/N	D/F	M/M	J/A	S/N	D/F	M/M	J/A	S/N	D/F
Melosira granulata (Ehr.) Ralfs *continued*																					
7A.	O	R	O	O	O	O	O	O	L	M	L	X	R	R	X						
8.	X	R	O	X	R	R	X	X	R	R	R	R	R	X	X						
9.	X	X	O	X	X	M*	X	X	R	X	R	X	X	R	X						
Chaffey Dam																					
1.										F*	L	L	F*	L	L	L	F*	L	L	R	M
2.										F*	F*	X	M*	L	L	L	M*	L	X	R	M*
.3.										F*	M*	R	M*	O	L	R	M*	L	X	R	M*
4.										F*	F*	R	R	O	L	R	M*	L	X	R	O
5.										O	O	O	O	O	R	R	M*	O	O	O	O
Navicula spp. (including *N. capitata* Ehr., *N. cuspidata* Kütz., *N. mutica* Kütz. and *N. radiosa* Kütz.)																					
Peel River																					
1.	L	L	O	R	L	R	X	L	R	O	R	R	O	L	R						
2.	L	L	O	R	L	R	L	L	X	O	L	L	O	M	L						
3.	X	L	O	X	R	L	R	R	L	O	L	L	L	L	L						
4.	L	L	O	R	L	L	R	L	L	L	L	L	M	M	L						
5.	R	L	O	R	R	L	L	L	L	L	L	L	O	O	L						
7.	O	R	O	O	O	O	O	O	M*	L	F*	M*	L	L	L						
7A.	O	L	O	O	O	O	O	O	M*	M*	M*	L	M*	M	F*						
8.	R	L	O	X	X	M*	L	L	M	M*	M	L	M*	M*	L						
9.	M*	M*	O	X	R	L	L	L	M	M	L	L	M	M	L						
Chaffey Dam																					
1.										X	R	R	X	R	L	L	R	R	R	L	L
2.										X	R	X	L	R	L	M	R	L	L	L	L
3.										R	M	L	L	O	L	M	R	R	R	M	L
4.										M	M	M*	X	O	M	M	R	R	X	L	R
5.										O	O	O	O	O	O	M	R	O	O	O	O

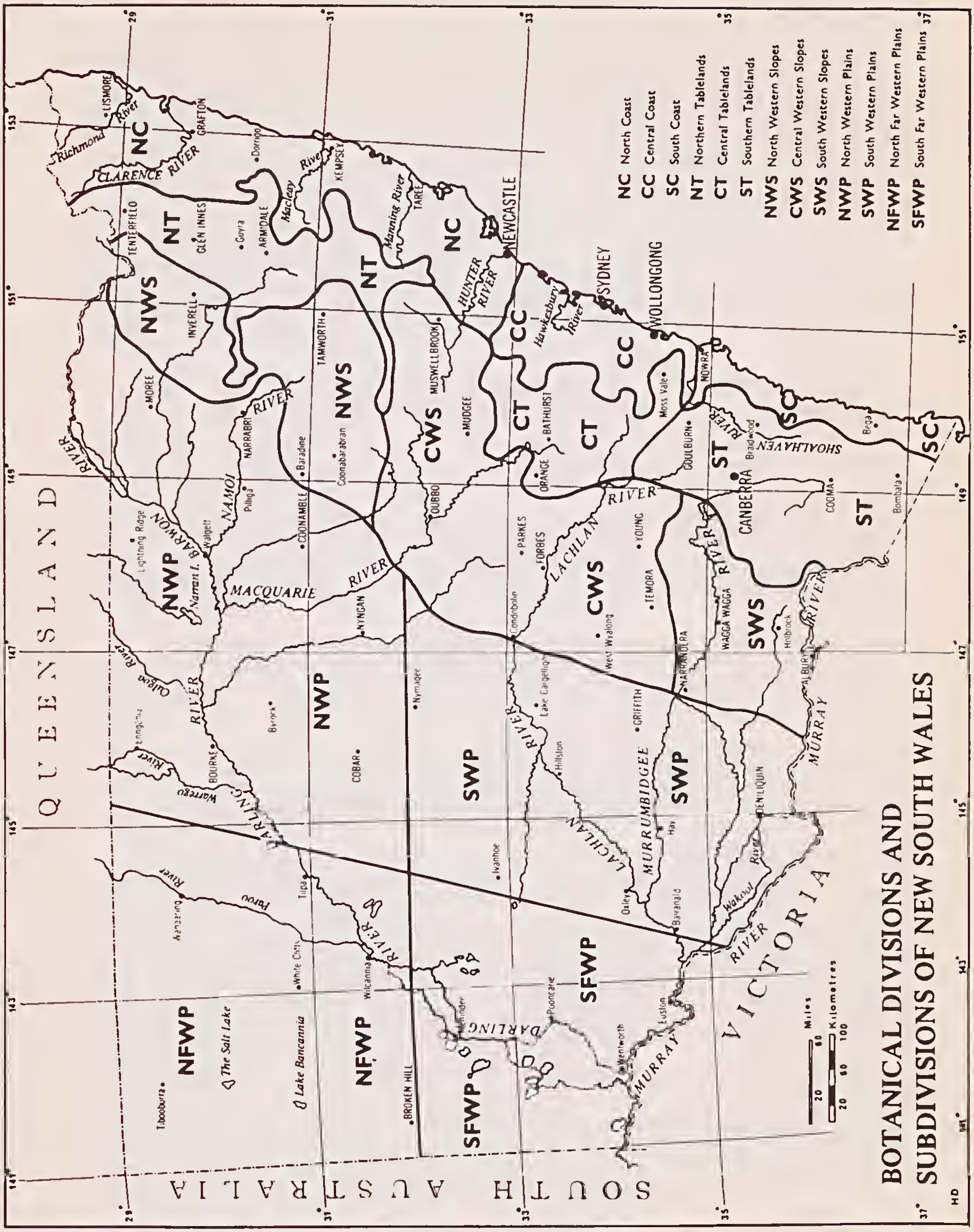
Nitzschia spp. (including *N. frustulum* (Kütz.)Grun. *N. linearis* W. Smith and *N. palea* (Kütz.) W. Smith)

Peel River																					
1.	X	L	O	L	L	L	R	M*	L	O	F*	F*	O	L	M*						
2.	X	L	O	L	L	L	M*	M	M	O	M*	M	O	M*	F*						
3.	X	L	O	L	L	L	L	F*	M*	O	F*	M	O	M*	M*						
4.	L	L	O	L	L	L	L	F*	M	L	F*	M*	F*	F*	F*						
5.	L	L	O	L	R	L	M	M*	M	L	M	M*	O	O	M*						
7.	O	O	O	O	O	O	O	O	L	L	M	L	L	L	L						
7A.	O	L	O	O	O	O	O	O	M*	L	F*	F	L	L	M*						
8.	L	L	O	L	X	M	F*	M*	F*	M*	F*	L	L	L	F*						
9.	L	L	O	L	L	L	F*	M*	F*	M*	M	L	M*	M	F*						
Chaffey Dam																					
1.										X	R	M	X	R	L	L	M	L	X	L	R
2.										X	R	X	L	L	L	L	M*	L	R	L	L
3.										R	L	R	R	O	L	M*	M*	L	X	L	L
4.										R	L	L	R	O	L	M*	M*	L	R	L	R
5.										O	O	O	O	O	O	L	M*	O	O	O	O

Rhoicosphenia curvata (Kütz.) Grun.

Peel River																					
1.	L	M*	O	L	L	R	R	L	R	O	L	L	O	L	L						
2.	L	L	O	R	L	R	L	L	R	O	L	L	O	O	L						
3.	M*	M	O	L	L	R	R	L	L	O	L	M	O	O	R						
4.	M	M*	O	M	L	M*	R	L	L	F*	M	M*	L	L	L						
5.	M*	M	O	L	R	L	L	L	R	O	L	M	O	O	L						
7.	O	R	O	O	O	O	O	O	R	M*	L	M*	M	L	L						
7A.	R	M*	O	O	O	O	O	O	L	L	M*	M*	M	M	M						
8.	M*	M*	O	L	L	L	L	M	M	M	M*	F*	F*	M	L						
9.	L	M	O	L	L	L	L	L	M	M*	M*	L	M	M	M						

Station No.	Year/Quarter																				
	1978				1979				1980				1981				1982				1983
	D/F	M/M	J/A	S/N	D/F	M/M	J/A	S/N	D/F	M/M	J/A	S/N	D/F	M/M	J/A	S/N	D/F	M/M	J/A	S/N	D/F
Rhoicosphenia curvata (Kütz.) Grun. *continued*																					
Chaffey Dam																					
1.										X	R	R	R	R	R	R	L	R	R	L	M
2.										X	R	X	R	R	R	R	R	R	X	X	L
3.										R	R	M*	R	O	R	R	R	R	X	R	R
4.										R	L	R	O	O	R	R	R	R	X	R	R
5.										O	O	O	O	O	R	R	R	O	O	O	O
Synedra ulna (Nitzsch) Ehr.																					
Peel River																					
1.	L	L	O	M*	M	R	R	X	R	O	L	M*	O	M*	R						
2.	L	L	O	R	R	L	L	R	R	O	L	M*	O	X	M						
3.	M	M*	O	X	R	M*	R	R	L	O	L	L	O	M*	R						
4.	L	M*	O	R	L	L	R	R	M*	L	M*	M	L	M*	L						
5.	L	L	O	R	R	L	M*	L	L	R	R	M*	O	R	R						
7.	X	R	O	O	O	O	O	O	M*	L	M*	F*	M*	M*	M*						
7A.	X	L	O	O	O	O	O	O	M*	R	M*	F*	R	M*	M						
8.	L	F*	O	L	L	M*	L	L	L	M*	M	M*	M	M	L						
9.	M*	L	O	R	L	L	L	L	L	M	F*	F*	M*	M*	M						
Chaffey Dam																					
1.										X	X	L	R	L	R	R	L	L	L	L	L
2.										X	R	X	L	L	R	L	L	L	L	L	L
3.										X	R	L	X	O	R	R	R	R	X	F*	L
4.										R	R	L	R	O	L	R	R	L	R	R	R
5.										O	O	O	O	O	R	R	R	O	O	O	O



For explanation and description of the Botanical Divisions and Subdivisions of New South Wales see Anderson, R.H. (1961). Introduction. *Contr. New South Wales Natl. Herb. Fl. New South Wales* Nos. 1–18, pp. 1–15.

NOTICE TO CONTRIBUTORS

Papers dealing with all aspects of vegetation mapping and plant community descriptions, including floristic lists and ecological data of value for land use and environmental impact studies, are considered for publication in *Cunninghamia.* Papers dealing primarily with New South Wales or with comparative data from New South Wales and neighbouring states will be given preference over those dealing exclusively with other Australian states or other countries. The latter will be considered on the basis of their relevance to New South Wales. Articles of limited scope may be published as Reports or Short Communications. Papers are refereed.

Submission of a paper implies that the results reported have never been published and are not being considered for publication elsewhere.

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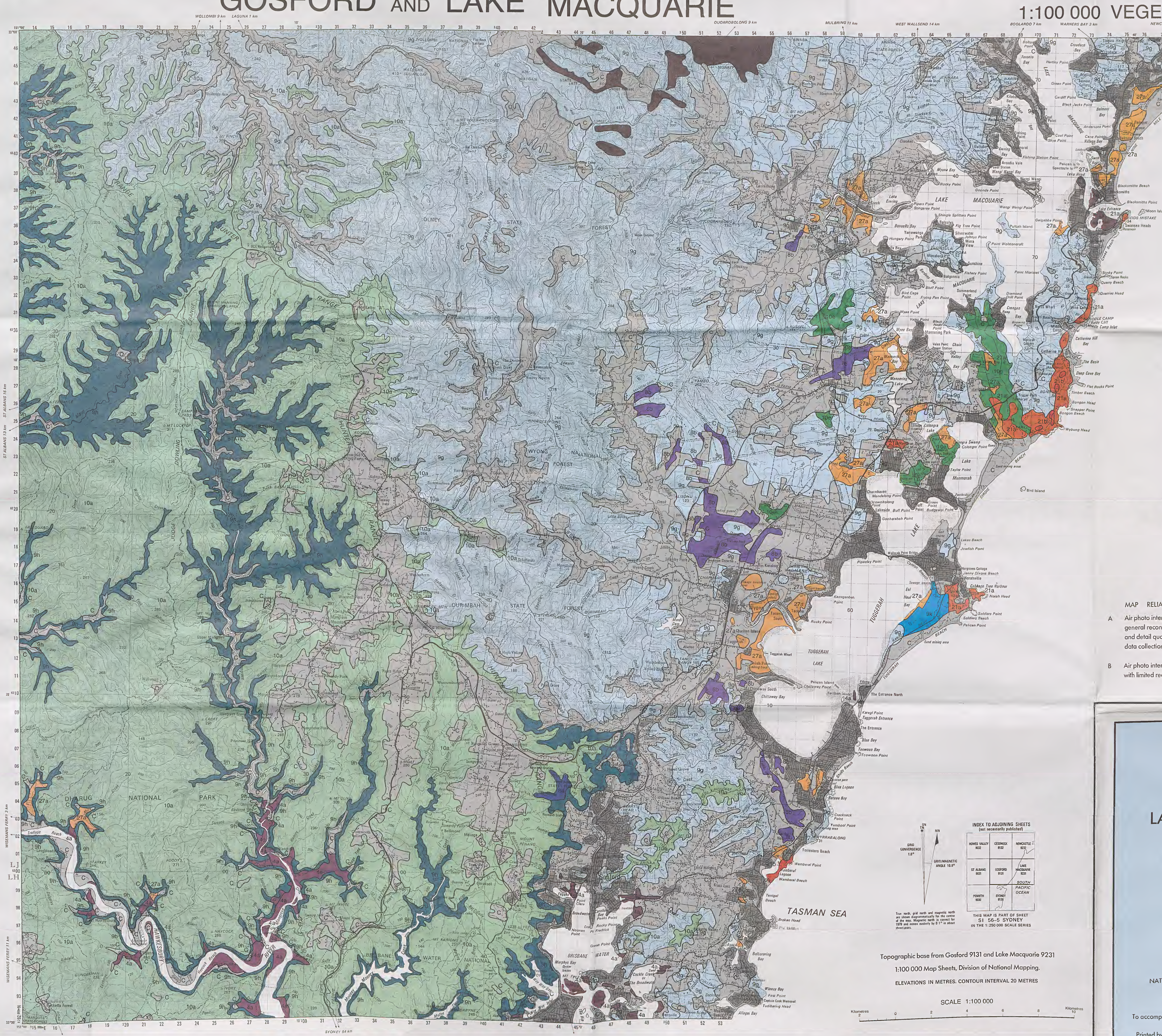
GOSFORD AND LAKE MACQUARIE

1:100 000 VEGETATION SERIES

PLANT COMMUNITY DESCRIPTIONS

Map unit	Structural formation	Main Canopy species	Geology	Occurrence
4a	OPEN-SCRUB	*Avicennia marina*	Quaternary alluvium	Estuarine mudflats, regular tidal inundation
	HERBLAND	*Sarcocornia quinqueflora*		Occasional tidal inundation
	RUSHLAND	*Juncus kraussii*		Infrequent tidal inundation
	LOW OPEN-FOREST	*Casuarina glauca,* *Baumea juncea*		Poorly-drained, some saline influence
6a	TALL OPEN-FOREST	*Eucalyptus saligna,* *Syncarpia glomulifera,* *Angophora costata,* *Eucalyptus pellita*	Clifton Sub-group Gosford Formation	Deep, sheltered gullies, south-east aspects
8a	CLOSED-FOREST	*Ceratopetalum apetalum,* *Doryphora sassafras,* *Acmena smithii,* *Livistona australis.* Emergents— *Eucalyptus deanei,* *Syncarpia glomulifera*	Narrabeen Group	Sheltered gullies, fertile soils
8b	CLOSED-FOREST	*Melaleuca linariifolia,* *M. styphelioides,* Emergents— *Eucalyptus robusta,* *E. longifolia*	Quaternary alluvium	Poorly-drained creek flats
	SCRUB	*Melaleuca ericifolia, M. sieberi,* *M. decora, M. nodosa,* *M. linariifolia, M. thymifolia*		Poorly-drained flats often on poor soils
9g	OPEN-FOREST	*Angophora costata,* *Eucalyptus gummifera,* *E. capitellata,* *E. pilularis.*	Narrabeen Group and Permian sandstones	Gentle slopes, ridge tops and valley floors
		E. maculata, *E. umbra,* *E. siderophloia,* *E. punctata*		Steeper slopes on ridge sides
9h	OPEN-FOREST	*Eucalyptus deanei,* *E. acmenoides,* *Angophora floribunda,* *Syncarpia glomulifera.*	Narrabeen Group	Valleys, or lower valley slopes, sheltered aspects
		Angophora floribunda, *Eucalyptus punctata,* *E. tereticornis,* *E. eugenioides,* *Allocasuarina torulosa*		Dry northern or western aspects
9k	OPEN-FOREST	*Angophora costata*	Quaternary sand dunes	Sheltered coastal dunes, North Entrance
10a	OPEN-FOREST/ WOODLAND	*Eucalyptus piperita,* *Angophora costata*	Hawkesbury Sandstone	Sheltered hillsides gullies
	LOW WOODLAND	*Eucalyptus gummifera,* *E. eximia,* *E. punctata,* *E. haemastoma*		Ridges, plateaux and dry exposed hillsides
	OPEN SCRUB	*Banksia ericifolia,* *Hakea teretifolia*		Poorly-drained situations
		Angophora hispida, *Lambertia formosa,* *Banksia serrata*		Dry rocky ridges, shallow soil
	OPEN-HEATH	*Allocasuarina distyla,* *Baeckea* spp., *Darwinia* spp.		Patches in isolated depressions on rock platforms
	SEDGELAND	*Cyperaceae and* *Restionaceae,* *Banksia robur*		Swampy organic soils with impeded drainage
10e	WOODLAND	*Eucalyptus haemastoma*	Clifton Sub-group	Broad low ridges with poor soils
21a	OPEN-HEATH	*Melaleuca nodosa,* *Allocasuarina distyla,* *Lambertia formosa,* *Banksia oblongifolia,* *Hakea teretifolia*	Clifton Sub-group/ Permian coal measures	Shallow soils or exposed situations, generally coastal
	GRASSLAND	*Themeda australis*		Headlands
	SEDGELAND	*Melaleuca thymifolia,* *Leptospermum juniperinum,* *Callistemon citrinus*		Poorly-drained sites
21b	OPEN-HEATH	*Banksia aemula,*	Quaternary Aeolian sand (Pleistocene)	Coastal headlands
	CLOSED-SCRUB	*Leptospermum laevigatum,* *Banksia integrifolia,* *Acacia longifolia*	Aeolian sand (Recent)	Coastal dunes
	LOW CLOSED-FOREST	*Cupaniopsis anacardioides,* *Livistona australis*		Lee side of larger dunes
27a	SEDGELAND	*Eleocharis* spp. *Baumea* spp. *Juncus* spp. *Alisma plantago-aquatica,* *Philydrum lanuginosum,*	Quaternary alluvium	Floodplains or behind dune systems where soils are periodically waterlogged
		Phragmites australis		Brackish water
	CLOSED-SCRUB	*Melaleuca ericifolia,* *Gahnia clarkei*		Shorter periods of inundation and waterlogging
	OPEN-FOREST	*Melaleuca quinquenervia,* *Casuarina glauca,* *Eucalyptus robusta,* *E. amplifolia*		
C	CLEARED	Native vegetation has been largely removed for agricultural or suburban development but remnant vegetation of varying size and condition may remain.		



GN TN MN
GRID CONVERGENCE 1.0°
GRID/MAGNETIC ANGLE 10.8°

True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 1979 and moves easterly by 0·1° in about three years.

INDEX TO ADJOINING SHEETS
(not necessarily published)

HOWES VALLEY 9032	CESSNOCK 9132	NEWCASTLE 9232
ST ALBANS 9031	GOSFORD 9131	LAKE MACQUARIE 9231
PENRITH 9030	SYDNEY 9130	SOUTH PACIFIC OCEAN

THIS MAP IS PART OF SHEET
SI 56–5 SYDNEY
IN THE 1:250 000 SCALE SERIES

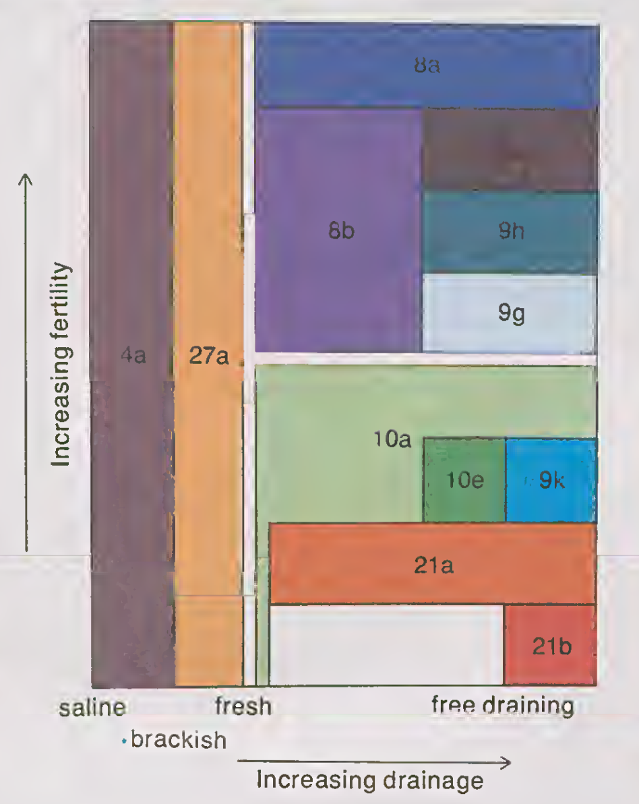
Topographic base from Gosford 9131 and Lake Macquarie 9231
1:100 000 Map Sheets, Division of National Mapping.

ELEVATIONS IN METRES. CONTOUR INTERVAL 20 METRES

SCALE 1:100 000

Kilometres 2 0 2 4 6 8 Kilometres 10

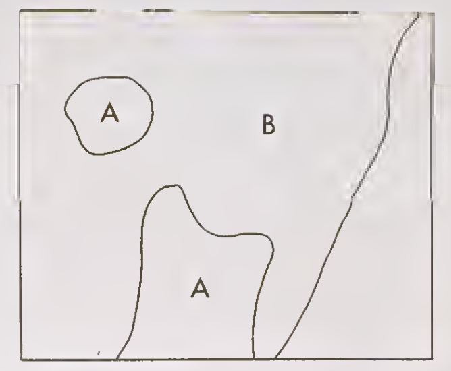
Schematic diagram showing relative positions of map units along inferred soil fertility and drainage gradients



MAP RELIABILITY

A Air photo interpretation, general reconnaissance, and detail quantitative data collection.

B Air photo interpretation, with limited reconnaissance.



VEGETATION of the GOSFORD and LAKE MACQUARIE area

by D.H. Benson

Compiled and prepared at the

NATIONAL HERBARIUM OF NEW SOUTH WALES,

ROYAL BOTANIC GARDENS, SYDNEY

To accompany CUNNINGHAMIA VOLUME 1, NUMBER 4, 1986

Printed by the Central Mapping Authority of New South Wales

Vegetation map of the Eurunderee area. The map used was compiled from 1:25 000 maps published by Central Mapping Authority of New South Wales (Bombah Point 1977, Myall Lakes 1977, Seal Rocks 1974). The map was compiled using aerial photographs (New South Wales Department of Lands) and ground traverses. The photographs were flown at 16 000 feet (4 877m) above sea level using a lens of 114.44 mm in focal length. Those of the Port Stephens area (series 1188) were flown on 18 August 1963 and those for the Bulahdelah-Forster area (series 1196) in January 1964.

CUNNINGHAMIA **Volume 1 (4)** **1986**

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